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Publication date:
2015

Document Version
Publisher's PDF, also known as Version of record

Link to publication in Tilburg University Research Portal

Citation for published version (APA):
Mannak, R. (2015). *To repeat or not to repeat: A temporal perspective on repeated collaboration in R&D consortia*. Ridderprint.

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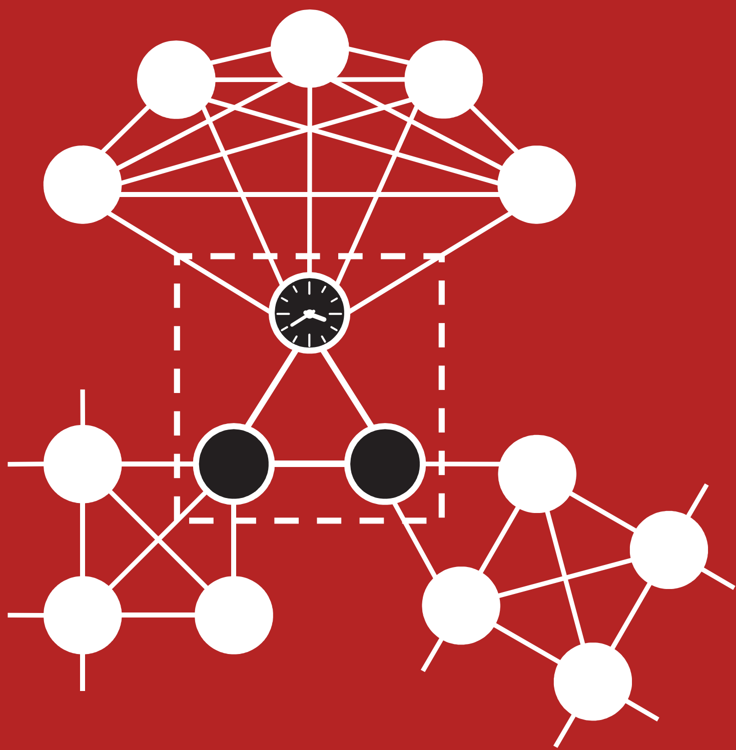

Remco Stefan Mannak

TO REPEAT OR NOT TO REPEAT:

A TEMPORAL PERSPECTIVE ON

REPEATED COLLABORATION IN R&D CONSORTIA

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Cover: Ridderprint BV, the Netherlands
Printing: Ridderprint BV, the Netherlands

ISBN **978-94-6299-249-8**

To Repeat or Not to Repeat:
A Temporal Perspective on Repeated Collaboration in R&D Consortia

Proefschrift

ter verkrijging van de graad van doctor aan Tilburg University
op gezag van de rector magnificus, prof. dr. E.H.L. Aarts,
in het openbaar te verdedigen ten overstaan van een door het college voor promoties
aangewezen commissie in de aula van de Universiteit op

maandag 21 december 2015 om 10.15 uur

door

Remco Stefan Mannak

geboren op 5 november 1983 te Oosterhout

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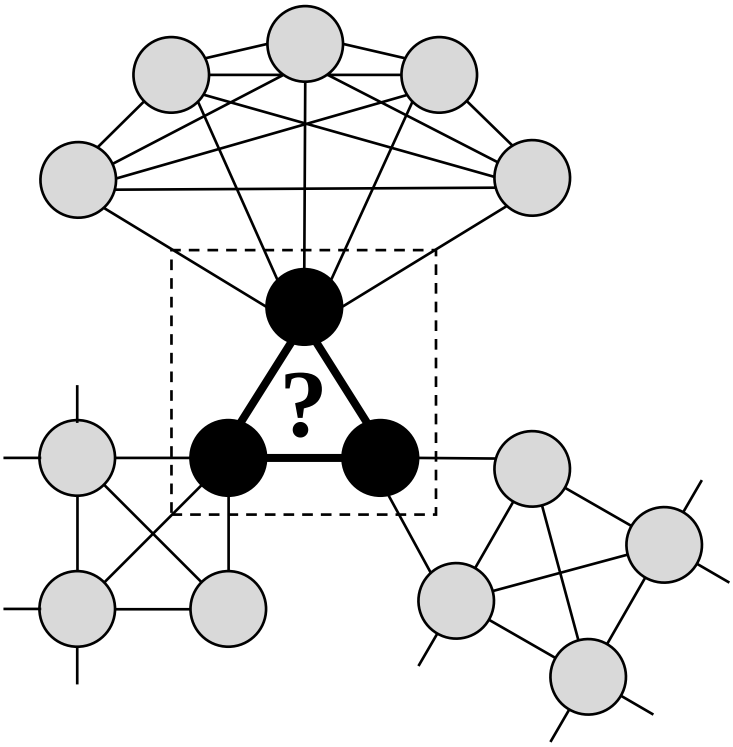
CHAPTER 1

TO REPEAT OR NOT TO REPEAT: THE QUESTION



1.1 SETTING THE STAGE

This dissertation introduces a temporal perspective on repeated collaboration in R&D consortia. Repeated collaboration is one of the many ways in which organizations create flexible organizational forms, and simultaneously retain some stability in their relationships, in order to adapt to social, economic, and technological dynamics. Globalization, volatile markets, and rapidly changing technologies cause an increasing demand for organizations to collaborate with other organizations in R&D consortia. Such collaborations can provide firms access to heterogeneous resources, and can reduce production cycles and time to market (Álvarez, Marin, & Fonfría, 2009; Doz & Hamel, 1998; Hagedoorn & van Kranenburg, 2003; Meeus, Oerlemans, & Kenis, 2008; Powell, Koput, & Smith-Doerr, 1996; Schilling & Phelps, 2007). Universities – still the most important institutions of basic research – fulfill an increasingly prominent role in these R&D consortia (Meeus & Oerlemans, 2005; Meyer-Krahmer & Schmoch, 1998), particularly in early-stage precompetitive R&D (Liebeskind, Oliver, Zucker, & Brewer, 1996; Mazzucato, 2011; Oliver, 2004). The importance of university-industry collaboration is evident from the fact that in the UK alone, these partnerships are worth £3.9 billion in 2014 (Times Higher Education, 2015).

However, the transfer of academic knowledge to industrial firms and the utilization of basic research are far from self-evident. On the contrary, the knowledge infrastructure between universities and industry heavily depends on government interventions, both in terms of financing and proactive coordination (Hage & Meeus, 2006; Mazzucato, 2011). Mazzucato (2011) argues for instance:

> "Government's role in not only creating knowledge (through national labs and universities) but also mobilising resources, and allowing knowledge and innovations to diffuse across sectors and the economy, is key in this view, either through existing networks or by facilitating new ones. […] The state has a further role to play to lead the process of industrial development, developing strategies for technological advance in priority areas" (p. 69).

To shed more light on the potential roles of both the state and individual organizations in such innovation networks, this dissertation applies a longitudinal perspective on collaboration in R&D consortia granted by one of the oldest and most prominent Technology Programs for university-industry collaboration in the Netherlands.

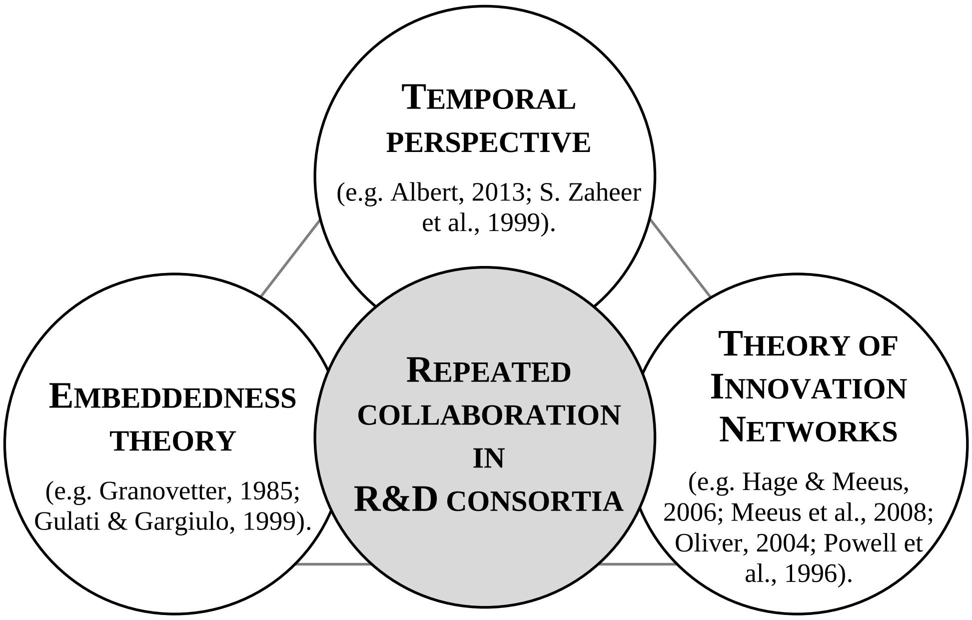
R&D consortia are temporary social entities that align joint activities of a consortium leader and consortium members – in our research setting a university representative and multiple representatives of industrial firms – to pursue both collective and individual goals and outcomes (Das & Teng, 2002; Oerlemans & Meeus, 2009). Collaboration in R&D-consortia is often conceptualized as the flexible side of the firm's R&D-portfolio, because it is time-bound and external to the focal organization (e.g. Adler, Goldoftas, & Levine, 1999; Tushman & O' Reilly, 1996). We argue that *repeated collaboration* in R&D consortia is indicative of another phenomenon, namely that even within the flexible form of the R&D consortia, organizations look for stability in their relationships over time. Repeated collaboration is defined as the repeated participation of (a subset of) the consortium leader and members in two or more subsequent consortia. Organizations that repeatedly collaborate with the same partners in successive consortia and extend the duration of their relations actively contribute to network stability, which can affect the innovation performance of both proximate and more distal organizations in the innovation network.

The collaborations between multiple university and industry partners in partially overlapping R&D consortia add up to field innovation networks. In this way, organizations become embedded in R&D consortia, which in turn become embedded in the wider field network. According to embeddedness theory, organizational actions and outcomes are enabled and constrained by their embeddedness in the wider web of social relations (Granovetter, 1985; Gulati & Gargiulo, 1999).

The relation between the social embeddedness of organizations in the wider inter-organizational networks and the innovation performance of these organizations has been widely investigated in prior research (e.g. Burt, 2005; Doz, Olk, & Ring, 2000; Meeus & Faber, 2006; Powell et al., 1996; Schilling & Phelps, 2007). However, less attention has been devoted to the dynamics of these networks (e.g. Ahuja, Soda, & Zaheer, 2012), particularly the cross-level interactions between the organization, consortium, and network levels (Brass, Galaskiewicz, Greve, & Tsai, 2004; Moliterno & Mahony, 2010; Raab, Lemaire, & Provan, 2013; A. Zaheer, Gözübüyük, & Milanov, 2010).

This dissertation is a response to these previous calls for time-sensitive theories of collaboration (e.g. Albert, 2013; Ancona, Goodman, Lawrence, & Tushman, 2001; Gersick, 1991; S. Zaheer, Albert, & Zaheer, 1999) and examines the dynamics and innovation performance of socially embedded organizations. Our temporal perspective allows us (I) to disentangle distinct time utilization strategies of organizations in R&D consortia; (II) to shed more light on the explanatory mechanisms of embeddedness theory including a temporal lens; (III) to examine the importance of the timing of actual resource inputs for innovation success; and (IV) to explore the distribution of stability and flexibility across the core and the periphery of the field innovation network. We unite and extend embeddedness theory and theory of innovation networks with a temporal perspective (Figure 1).

Figure 1: Theoretical Perspectives



The general research question addresses the antecedents and consequences of repeated collaboration in R&D consortia:

To what extent does past social embeddedness influence the timing of repeated ties in R&D consortia, and to what extent do these repeated ties influence the organization and consortium innovation success?

1.1.1 Embeddedness Theory

> "Actors do not behave or decide as atoms outside a social context, nor do they adhere slavishly to a script written for them by the particular intersection of social categories that they happen to occupy. Their attempts at purposive action are instead embedded in concrete, ongoing systems of social relations" (Granovetter, 1985, p. 487).

The above quotation introduces the core argument of social embeddedness theory (Granovetter, 1985; Gulati & Gargiulo, 1999). On the one hand, social embeddedness can enable organizational actions through information advantages, reduced potential for opportunism, development of mutual trust, and potential for learning and knowledge transfer (e.g. Gulati, 1995a; Gulati & Gargiulo, 1999; Stuart, 2000; Uzzi, 1997). On the other hand, social embeddedness can also impede organizations, due to information redundancy, fear of over-dependency, and creative lock-ins (Li & Rowley, 2002; Skilton & Dooley, 2010; Uzzi, 1997). However, social embeddedness is not static, but transforms both with the relational choices of actors and with the dynamics of the wider inter-organizational networks (Gulati & Gargiulo, 1999). Studying these dynamics is of central relevance for innovation networks (e.g. Powell, White, Koput, & Owen-Smith, 2005), particularly when these networks are shaped by time-bound R&D consortia (Bakker, Boroş, Kenis, & Oerlemans, 2013; Bakker & Knoben, 2015; Das & Teng, 2002) that offer opportunities to spread risks associated with longer term R&D trajectories (Das & Teng, 2002; Lavie, Kang, & Rosenkopf, 2010; Ring, Doz, & Olk, 2005).

Previous research examined dynamics at the network level (e.g. Koka, Madhavan, & Prescott, 2006; Powell et al., 2005) and the dyad level (e.g. Baum, McEvily, & Rowley, 2012; Moody, 2002; Ring & Ven, 1994), but studies that combine dynamics at different levels are relatively rare (e.g. Gulati, Sytch, & Tatarynowicz, 2012; Knoben, Oerlemans, & Rutten, 2006). The rareness of this type of research is attributed to the severe data requirements (Moliterno & Mahony, 2010; Raab et al., 2013). The examination of dynamics at different levels of analysis in a single study, however, can provide essential insights in the collaboration and innovation processes in these consortia and networks by decomposing the interrelatedness of dynamics at the organization, consortium, and network level (Ahuja et al., 2012). Such an approach is thus an important step by further overcoming the limitations of the static character of earlier studies investigating the influence of network characteristic on innovation success.

1.1.2 Theory of Innovation Networks

Theory of innovation networks is about how organizations collaborate in order to create value by developing new products or services or adapting existing products and services in an economically viable way. Ambidexterity theory (e.g. Adler et al., 1999; Benner & Tushman, 2003; March, 1991), and theory on innovation networks often times distinguish two interrelated tasks, exploration and exploitation (e.g. Gilsing, Lemmens, & Duysters, 2007; Oliver, 2001, 2004). Whereas exploration is about the "[…] general screening and the search for new knowledge […for which…] interorganizational heterogeneity and diversity in capabilities and knowledge are required […]", exploitation is about "[…] the actual capture of value, which depends on rents from knowledge and discoveries" (Oliver, 2004, p. 155). Accordingly, exploration is often times associated with inter-organizational collaboration while exploitation rather demands internalization of knowledge and competition over the appropriation of the achieved insights (Oliver, 2001, 2004). However, due to increased speed of technological developments and volatility of markets, competition more and more often occurs between consortia in which organizations collaborate to shorten production cycles and time to market (Doz & Hamel, 1998; Gilsing et al., 2007; Gomes-Casseres, 1996). This development creates a growing demand for research that addresses not only the innovation performance implications of embeddedness of organizations in R&D consortia (e.g. Das & Teng, 2002; Doz et al., 2000; Evan, 1993), and in inter-organizational networks (e.g. Powell et al., 1996; Schilling & Phelps, 2007), but also the innovation performance implications of the embeddedness of the consortium in the wider network. Our research on the interplay between dynamics and innovation outcomes at these different levels of analysis – organization, consortium, and network level – adds considerable refinement to the understanding of inter-organizational collaboration in R&D consortia and innovation networks.

1.1.3 Temporal Perspective

Several prior studies have called for time-sensitive theories of collaboration (Ancona et al., 2001; Marks, Mathieu, & Zaccaro, 2001; S. Zaheer et al., 1999), but the timing of repeated ties has remained underexplored. The reason for this lack of time-sensitive research is twofold, firstly the difficulty of collecting adequate longitudinal data, and secondly the lack of theories on the timing of repeated ties. The timing of repeated ties refers to a discrete point in time at which members of a social network repeat their initial ties in a subsequent tie. This dissertation hones in on this void and introduces a temporal perspective on repeated collaboration. We build on recent work of S. Zaheer et al. (1999) and Albert (2013) that provides ground to explicate several implicit timing assumptions in embeddedness theory and innovation theory, e.g. that repeated collaboration occurs in a sequential fashion (e.g. Cattani, Ferriani, Negro, & Perretti, 2008; Gulati, 1995a; Kale, Singh, & Perlmutter, 2000), or that ties instantly facilitate knowledge and resource flows (Borgatti & Halgin, 2011; Borgatti, Mehra, Brass, & Labianca, 2009; Podolny, 2001).

This dissertation zooms in on repeated collaboration in R&D consortia for a number of reasons. First, repeated collaboration is one way in which organizations can actively extend the duration of their relations beyond the temporal boundaries of a single consortium. It shows the extent to which organizations look for stability in their relationships over time in flexible inter-organizational forms like R&D consortia. Second, repeated collaboration is at the heart of social embeddedness theory, because repeated ties are supposed to provide the most reliable source of partnering information (Granovetter, 1985). However, the timing of such repeated ties has been left virtually unexplored. Third, organizational decisions to repeat ties are believed to be better informed and less random than initial tie formation decisions, and can have more enduring implications for the development of the wider inter-organizational network (Dahlander & McFarland, 2013). Fourth, examing repeated ties allows for a temporal assesment of one central assumptions of network theory, that is the transmission of knowledge and resoures through inter-organizational relations (Borgatti et al., 2009; Rawlings, McFarland, Dahlander, & Wang, 2015). The dissertation adds a temporal perspective to previous research on repeated collaborations (e.g. Goerzen, 2007; Gulati, 1995a, 1995b; Zheng & Yang, 2015), and presents an extension of embeddedness theory (e.g. Granovetter, 1985; Gulati & Gargiulo, 1999), theory on R&D consortia (e.g. Doz et al., 2000; Ring et al., 2005), and theory on innovation networks (e.g. Liebeskind et al., 1996; Meeus & Faber, 2006; Meeus et al., 2008; Oliver, 2004; Powell et al., 1996; Schilling & Phelps, 2007).

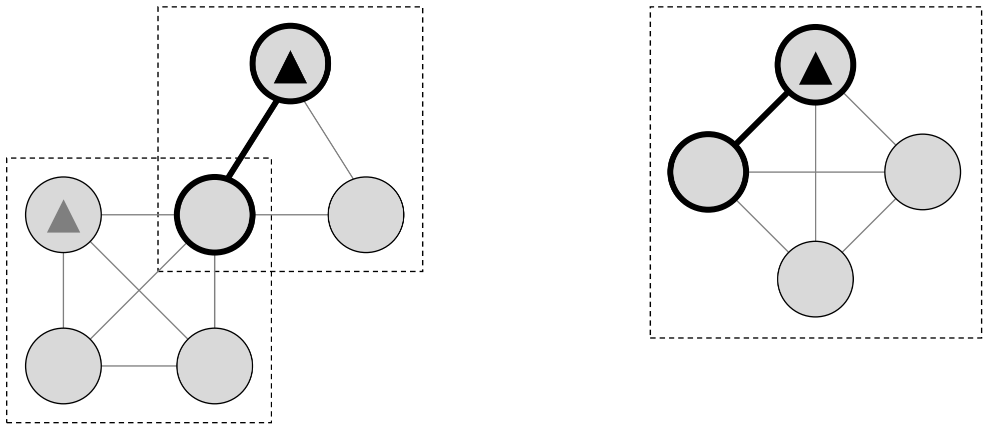
1.2 Research Setting

In this dissertation, we apply a mixed methods approach and combine longitudinal analyses on collaboration in R&D consortia on the basis of secondary data with qualitative assessments of primary data from 51 interviews with consortium leaders and members. All consortia in the analyses were funded by one of the oldest Dutch governmental funding programs that foster R&D collaboration between universities and industry. The Technology Program started in 1981 and is still ongoing. We acquired the secondary data from annual evaluation reports, so-called utilization reports, which the funding agency has published 5 years and/or 10 years after the consortium start. These reports provide information on the consortium membership lists, consortium goal, project descriptions, start year, end year, allocated funding and consortium success.

The consortia consist of an academic consortium leader who is affiliated with one of the Dutch Universities, mostly Technical Universities or Science Departments of General Research Universities, and a user committee with an average of 4 to 5 representatives of industrial firms or service providers. The consortium leader is considered as a unique representative of his/her university. The consortia carry out publicly funded R&D projects, hence the consortium leader and members meet at least twice a year to assess the project progression. The funding agency allows for a maximum project duration of approximately 6 years. In this dissertation, collaboration between university and industry representatives beyond the boundaries of the Technology Program is not taken into consideration. Furthermore, our analyses are restricted to consortia whose application for research funding were granted. A committee of experts assesses the applications with respect to the scientific quality and utilization value. Besides these two assessment criteria, there are no formal provisions to favor one application over another. In the analyses, we controlled for unobserved historical fluctuations and field network heterogeneity by means of observation year dummies and application area dummies.

In Chapters 2 and 3, we used data on all 1715 multi-partner R&D consortia that were established between 1983 and 2004. Data on consortia that started after 2004 were not available at the time of the analyses. Data on consortia established between 1981 and 1982 were excluded from the analyses, because the number of observations per application area was so low in these first two years that most of these observations dropped out of the analyses. In Chapter 2, the R&D consortium is the unit of analysis and we examined the timing of repeated ties for different types of actor sets. In Chapter 3, we focused on the dyadic tie between the university and industry representative formed through the R&D consortium. We examined tie formation and repetition of the dyad as function of past social embeddedness. The raw data that we extracted from the utilization reports represents two-mode network data. Figure 2 visualizes repeated collaboration between a consortium leader and a consortium member in two subsequent R&D consortia at t_0 and t_1. Ties between organizations result from joint participation in the same consortium and ties between consortia result from overlapping members with other consortia.

Figure 2: Repeated Collaboration in R&D Consortia



T0 **T1**

Consortium leader; Consortium member; Alter; Consortium.

In Chapters 4 and 5, we examined the effects of repeated collaboration and network stability on the innovation success of the R&D consortia. Given the additional data requirements for the analyses in these two chapters, we zoomed in on a subset of all funded R&D consortia, namely those in the Water sector in the Netherlands. We chose the Water sector, since it is one of the most innovative economic sectors in the Netherlands (Karstens et al., 2011; Maritiem Cluster in de Topsector Water, 2011), and it is characterized by a combination of stable actors and new entrants that collaborate in temporary R&D consortia (Levering, Ligthart, Noorderhaven, & Oerlemans, 2013). In Chapter 4, we again used data on consortia started between 1983 and 2004. In Chapter 5, we also include data on consortia in the first years of the funding scheme, because this chapter aims to provide a description of the full historical network development since the start of the Technology Program. We derived the values of the innovation success of the consortium from the utilization score of the consortium, rated by an external committee of specialists that was appointed by the funding agency. The utilization reports include evaluations with respect to the (I) member involvement; (II) product development, and (III) income achievement by the R&D consortium. In Chapter 4, we restricted the analysis to the latter two criteria, as the first partially overlaps with one of the predictors in this study. In Chapter 5, we used all three evaluation criteria that cover the objectives of the Technology Program. We did so because, from the perspective of the Technology Program and the government, that are central in Chapter 5, member involvement is an outcome criterion. However, from the perspective of consortium members, that are central in Chapter 4, member involvement is a process rather than an outcome indicator. For comparability reasons we conducted analyses per criterion in addition to the overall analyses. To examine the consistency of our findings, we conducted cross-chapter robustness tests in the sense that we included the independent variables of Chapter 3 in the analyses in Chapter 2 and vice versa, and similarly for Chapters 4 and 5.

In addition to the secondary data, we acquired primary data in 51 interviews based on a stratified sample of respondents from the above mentioned consortia in the Water sector in the Netherlands. The sample is stratified on actor type (consortium leader / member), subfield, consortium success and repeated collaboration experience. Some respondents (26 out of 51) have participated in multiple consortia, and therefore the interviews dealt with all the consortia in which they participated. The respondents represent in total 80 different consortia in the Water sector. The interview included questions with respect to the timing of repeated ties (for Chapter 2); the reasons to form and repeat ties (Chapter 3); resource contributions and innovation success (Chapter 4); and developments and events that affected inter-organizational collaboration in the field network in the Water sector (Chapter 5). We recorded, transcribed, and coded all interview material in an iterative process in which we worked back and forth between the emerging framework and the transcripts.

1.3 Structure of the Dissertation

The dissertation is structured along two dimensions, firstly the focus on antecedents versus consequences of repeated collaboration in R&D consortia, and secondly the focus on internal consortium characteristics, such as the type and number of actors involved in the consortium or their level of participation, versus the external embeddedness of the consortium and its members in the wider inter-organizational network. With respect to the first dimension in Chapters 2 and 3 of this dissertation, we examine the antecedents of repeated collaboration. We build on social embeddedness theory to explain the formation and repetition of ties through R&D consortia. In Chapters 4 and 5, we examine the consequences of repeated collaboration between consortium leaders and members in terms of the innovation success of the consortium and the involved member organizations. With respect to the second dimension in Chapters 2 and 4, the consortium is the unit of analysis and we focus on consortium characteristics as predictors in the model, e.g. the composition or experience of the actor set. In Chapters 3 and 5, we focus on the consortium and its members in relation to their position in the wider inter-organizational network.

Table 1: Structure of the Dissertation

	REPEATED COLLABORATION	
Level of Analysis	Antecedents	Consequences
Consortium	**Chapter 2**	**Chapter 4**
… in network	**Chapter 3**	**Chapter 5**

1.3.1 A Temporal Perspective on Repeated Collaboration

Chapter 2 of this dissertation investigates the implicit assumption in embeddedness theory that timing of repeated collaboration is homogeneous and mainly occurs in a sequential fashion, which leads to social embeddedness over time. We contribute to embeddedness theory (e.g. Granovetter, 1985; Gulati & Gargiulo, 1999; Uzzi, 1997), by exploring variance in timing of distinct types of repeated ties. Such variance in timing of repeated ties either results in the continuation of relationships, indicative of the development of social embeddedness over longer time periods, or in the intensification of the relationship by initiating repeated ties in parallel. The timing of repeated ties is associated with two distinct time utilization strategies (time extension and time compression strategy), and is related to the type and number of actors involved in repeated collaboration. The research question is:

> *RQ1: How does the likelihood of repeated ties unfold over time, and to what extent is the timing of repeated ties different for distinct types of involved actor sets?*

1.3.2 Towards a Time-Sensitive Theory of Embeddedness

In Chapter 3, we ask whether the formation of dyads and the repetition of dyads between a consortium leader and a member are impacted differentially by their past embeddedness. Past embeddedness captures the information and experience acquired with past collaborations and largely informs the decision on whether to repeat a relation (Granovetter, 1985; Gulati & Gargiulo, 1999). Embeddedness theory, however, does not distinguish between embeddedness effects on tie formation and on the repetition of existing ties. Therefore, it is implicitly assumed in the literature to date that effects of past embeddedness are stable over time, more specifically that effects of past embeddedness are equally strong for tie formation, and for repeating ties. We challenge this assumption and compare the effects of past embeddedness on the likelihood of tie formation and repetition at distinct points in time, that is: a) when the dyad is formed; b) when the repeat of any tie occurs briefly after the tie formation; c) when the repeat of any former tie occurs after tie termination. Next to relational, structural, and positional embeddedness (Gulati & Gargiulo, 1999; Uzzi, 1997), we also examine the effect of consortium embeddedness, i.e. the position of a consortium in its network, on the likelihood of tie formation and repetition. In this way, we explore the extent to which the consortium serves as social structure that embeds a newly formed dyad and modifies the effects of past embeddedness on the formation and repetition of ties. Simultaneously, we examine whether the consortium acts as social entity that becomes embedded in the wider inter-organizational network. The research question is:

> *RQ2: To what extent is the likelihood of present tie formation and future repeated collaboration between a consortium leader and a consortium member related to the temporal dynamic effects of past embeddedness in a network of organizations and consortia?*

1.3.3 A Contingency Model of Repeated Collaboration Experience and Innovation Outcomes

Chapter 4 provides a contingency theory of repeated collaboration in multi-partner R&D consortia, which is explored at the organization and the consortium level. Although past research has shown that repeated collaboration contributes to the performance of the inter-organizational collaborations (Gulati, 1995a; Ingram & Simons, 2002; Schwab & Miner, 2008; Zollo, Reuer, & Singh, 2002), some studies provide mixed or even contradictory results and show that repeated collaboration can cause creative lock-ins, inertia, and consortium failure (e.g. Goerzen, 2007; Li & Rowley, 2002; Polidoro, Ahuja, & Mitchell, 2011; Skilton & Dooley, 2010). To clarify this relation, we introduce the contingency ‘level of participation’, that is the extent to which consortium members mobilize their resources to contribute to the consortium activities. Our central thesis is that organizations with moderate levels of repeated collaboration experience are more likely to mobilize their resources and thereby increase the innovation success (mediation), and if they do, these organizations are more likely to benefit from their resource contributions (moderation) compared to organizations with low or high levels of repeated collaboration experience. Testing this thesis, we explore one of the central assumptions of network theory (Ahuja et al., 2012; Rawlings et al., 2015), that ties in networks are “pipes” that facilitate flows of knowledge and resources (Borgatti & Halgin, 2011; Borgatti et al., 2009; Podolny, 2001). The research question is:

> *RQ3: To what extent is organization and consortium innovation success related to repeated collaboration experience, and to what extent is this relation moderated and/or mediated by the level of participation of consortium members?*

1.3.4 "Don't Grab That Nucleus!"

In Chapter 5, we explore the relation between the positional stability of structurally differentiated actors, network dynamics, and innovation outcomes. We aim to advance our understanding of the interplay between dynamics at the organization and the field network levels in innovation networks, as recently placed on the research agenda (Ahuja et al., 2012; Amburgey, Al-Laham, Tzabbar, & Aharonson, 2008; Brass et al., 2004). Previous research on collaboration in innovation networks has demonstrated that a small-world structure facilitates innovation success (Burt, 2005; Lavie et al., 2010; Schilling & Phelps, 2007; Uzzi & Spiro, 2005). However, how dynamics at the organization level and the field network level complement small-worldliness in explaining innovation performance remains an understudied phenomenon. In this study, we synthesize small-worldliness and the stability of actor positions to provide insight in the success of innovation networks in the Dutch Water sector. We hereby pay special attention to actors that functions as central connectors. Firstly, we examine the extent to which the positional stability of individual organizations relates to the stability of the complete field network, and secondly we assess the effects of the distribution of stability and flexibility over the core and periphery of the field network in relation to the innovation performance of the involved R&D consortia. The research question is:

> *RQ4: To what extent is the development of a stable core in the R&D network related to the stability of the central connectors in the network, and to what extent does the development of this stable core influence the innovation outcome of the consortia in the network?*

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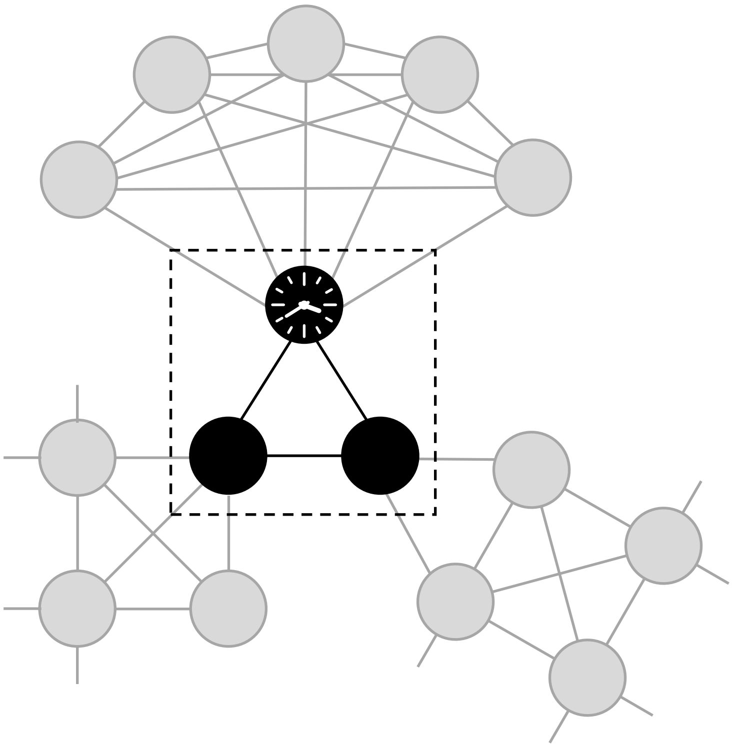
CHAPTER 2

A TEMPORAL PERSPECTIVE ON REPEATED COLLABORATION



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ABSTRACT

This study investigates the implicit assumption in embeddedness theory research that timing of repeated collaboration is homogeneous and mainly occurs in a sequential fashion, which leads to social embeddedness over time. Results of an event history analysis of the establishment of 1715 multi-partner R&D consortia over 22 years show that timing of repeated collaboration is heterogeneous, and concentrate at two points in time: the consortium start (parallel timing) and the consortium end (sequential timing). The timing of repeated ties is associated with two distinct time utilization strategies (time extension and time compression strategy), and depends on the type and number of actors involved in repeated collaboration. The study contributes to a temporal explanation of inter-organizational collaboration and presents an extension of embeddedness theory.

Previous versions of this chapter were presented at the 27th EGOS colloquium (Gothenburg, 2011), the 2nd Tilburg Conference on Innovation (Oisterwijk, 2012), the 28th EGOS colloquium (Helsinki, 2012), and the 2015 Annual Meeting of the Academy of Management (Vancouver, 2015).

2.1 INTRODUCTION

In this study, we develop a preliminary theory of the timing of repeated ties by investigating one of the central assumptions of the theory of social embeddedness. As Granovetter wrote: "[…] *continuing* economic relations often become overlaid with social content that carries strong expectations of trust and abstention from opportunism" (1985, p. 490, emphasis added). Granovetter implicitly recognizes the temporal dimension of embeddedness in the form of continuing relations that develop certain characteristics over time that facilitate cooperation. Granovetter's continuing relations - or more broadly social embeddedness - have become a theoretical cornerstone of social network research (e.g. Gulati & Gargiulo, 1999; Ring & Ven, 1994; Uzzi, 1997). However, the underlying temporal dimension has remained rather implicit (e.g. Marsden & Campbell, 1984, 2012; Mathews, White, Long, Soper, & Bergen, 1998), and has been seldom empirically tested in terms of the timing of repeated ties. Social embeddedness has been measured mostly with the number of repeated interactions over a certain time period. Most studies that apply this measure, count the number of repeated ties without specifying how these repeated ties are distributed over time. These studies nevertheless claim to capture the temporal processes discussed by Granovetter (e.g. Cattani, Ferriani, Negro, & Perretti, 2008; Gulati, 1995a; Kale, Singh, & Perlmutter, 2000). Therefore, very little is known to date with respect to the distribution of repeated collaborations over time, and what explains a particular distribution, i.e. when and why do actors repeat a collaboration?

In order to shed more light on the timing of repeated ties, we discuss the prevalent views put forward in the literature and extend them in such a way that we are able to capture the timing of repeated ties within predetermined time frames. Subsequently, we advance a taxonomy of repeated ties to provide an explanation for the heterogeneity in the timing of repeated ties. The timing of repeated ties refers to a discrete point in time at which members of a social network repeat their initial ties in a subsequent tie. We argue that, even if the number of repeated ties is identical, their timing can point to distinct relational processes: the intensification of the ongoing relationships (due to a temporal concentration of partially overlapping repeated ties) or the extension of its duration (in case of sequential repeated ties).

Despite several calls for time-sensitive theories of collaboration (Ancona, Goodman, Lawrence, & Tushman, 2001; Marks, Mathieu, & Zaccaro, 2001; Zaheer, Albert, & Zaheer, 1999), research on the antecedents of timing of repeated ties is virtually absent to date. There are two related reasons that explain why the phenomenon is underexplored in organizational sociology in general as well as in network studies in particular. First, the difficulty to collect adequate longitudinal data makes exploring the timing of repeated ties burdensome and highly complex. Second, a lack of theory covering inter-organizational phenomena such as the timing of repeated ties impedes the accumulation of knowledge on this topic. This chapter hones in on this void in network studies as it is based on a unique longitudinal dataset and addresses the question: How does the likelihood of repeated ties unfold over time, and to what extent is the timing of repeated ties different for distinct types of involved actor sets?

We contribute to embeddedness theory (e.g. Granovetter, 1985; Gulati & Gargiulo, 1999; Uzzi, 1997), by exploring variance in timing of distinct types of repeated ties. Such variance in timing of repeated ties either results in the continuation of relationships, indicative of the development of social embeddedness over longer time periods, or in the intensification of the relationship by initiating repeated ties in parallel. Whereas previous research mainly examined the number of repeated ties, we trace the timing of four different types of repeated ties up to 10 years after the first tie was initiated. We therefore introduce a temporal perspective to Granovetter's (1985) embeddedness theory. Variance in timing also implies actors' variance in making choices. In order to explain this variance in the decisions on the timing of repeated collaboration we explore specific contingencies. We thus extend Granovetter's (1985) initial approach to combine structure and agency in explaining human behavior to the formation of ties over time. We hereby answer the call by Emirbayer and Mische (1998) for a sociological perspective on "how agency interpenetrates with and impacts upon the temporal-relational contexts of action" (p. 1012).

2.2 University-Industry Collaboration

In this chapter, we explore a particular type of tie: R&D consortia (further on consortia) consisting of a consortium leader from a university and industry partners. In those university-industry ties, knowledge and research facilities are shared and exchanged, in order to produce technology that fits the demands of industry. The innovation network spawned by such collaboration connects industrial R&D and university research in which a blend of scientific, product, and process requirements have to be met. Typically such exchange induces a two-way alignment of rather different institutional logics including distinct incentive structures (extrinsic vs intrinsic), performance metrics (profit rates; reputation scores/rankings), and features of the production process (time to market, highly controlled, multiple stakeholders vs time to journal, loosely controlled, few stakeholders) (e.g. Cyert & Goodman, 1997; Meyer-Krahmer & Schmoch, 1998). Finding reputable scientific partners to work with is one thing, but sustaining and repeating these relations is yet another challenge. Especially with an eye on temporality, university-industry collaborations are interesting, because universities and industry typically do have different processes and time horizons, and henceforth the identification of the heterogeneity in timing strategies of repeated collaboration is a crucial topic.

2.3 ELABORATING EMBEDDEDNESS THEORY (ET): TIME AND TIMING

Repeated collaboration is defined as the repeated participation of the same set of actors in two or more subsequent consortia. Accordingly, the *timing* of repeated collaboration refers to a discrete point in time, relative to the start of the focal consortium, after which (a subset of) the members start a new consortium. Repeated collaboration is a central notion in the literature on inter-organizational networks, which is often times used as a proxy for social embeddedness (e.g. Gulati & Gargiulo, 1999), because it reduces opportunism in alliances (e.g. Gulati, 1995a; Parkhe, 1993), reduces capital costs of lending (e.g. Podolny, 1993; Uzzi, 1999), enhances richness of information exchange (Kenis & Oerlemans, 2008; Smith-Doerr & Powell, 2005), and improves legitimacy (Cattani et al., 2008), due to the development of trust over time (Gulati, 1995a), and provides potential for learning and knowledge transfer and integration in consortia (e.g. Stuart, 2000). As we are especially interested in temporal dynamics of repeated collaboration, an overview of the ten most cited studies addressing time and timing of repeated collaboration is presented in Table 1.

From this overview one can infer that, so far, 'time' is alluded to in Embeddedness Theory (ET) research but in a rather implicit way. Mostly the temporal dimension for repeated ties is conceptualized as the extension of the duration of the collaboration, and why 'it takes time' to decide to repeat a collaboration with the same partners. All ten studies refer to the temporal aspect of repeated collaboration often times referring to social embeddedness. In general, these studies include two types of mechanisms through which social embeddedness can affect economic action *over time*: (I) over time, ego (organizations) can better assess the relational risks (e.g. the trustworthiness of the alter, the risk of opportunism); and (II) over time, ego can better assess the relational opportunities (e.g. the needs and capabilities of the alter, the potential for joint product development).

Based on the assessment of the temporal process, the featured studies are divided into three categories: The first category includes studies that assume repeated collaboration to be a valid and sufficient proxy for social embeddedness, without measuring the temporal process (e.g. Gulati & Gargiulo, 1999; Kale et al., 2000; Stuart, 2000). These studies neither provide measures for the elapse of time, nor for the timing of repeated collaboration, they simply count the number of repeated collaborations. The second category includes studies that consider repeated collaborations and time (e.g. relationship duration) to be equivalent proxies for social embeddedness (e.g. Larson, 1992; Parkhe, 1993; Uzzi, 1999). These studies both measure the number of repeated collaborations and the time elapsed since the consortium start, though as distinct terms. However, *the timing of* repeated collaborations is not examined in these studies. The third category includes only one study (Gulati, 1995b), that examines not merely the number of repeated collaborations but also *the timing* of repeated collaborations.

Table 1: Empirical Studies on Repeated Collaboration That Build on Granovetter (1985)

Publication[1]	Sample	Temporal process	Mechanism(s)	Timing of RC
(Gulati, 1995a)	2395 alliances	Discussed	"The most basic conclusion […] is that contracts chosen in alliance […] also depend on the trust that emerges between organizations over time through repeated ties" (p. 108)	N
(Parkhe, 1993)	111 alliances	Examined[2]	Perceived opportunistic behavior declines over time, as partners develop trust, mutual understanding, and insight in the partner´s ability and willingness to abide the agreement.	N
(Larson, 1992)	7 alliances (53 obs.)	Examined[3]	First, prior relations reduce uncertainty and establish expectations. Second, in a trial period, trust and reciprocity norms develop. Third, social control mechanisms evolve during a phase of strategic and operational integration.	N
(Kale et al., 2000)	212 alliances	Discussed	Repeated alliances generate trust and interaction, facilitate learning and information exchange, and reduce potential opportunistic behavior.	N
(Gulati, 1995b)	166 firms (7266 obs.)	Examined[4]	Once an alliance is in place, information about a partner's reliability, operations and opportunities enhance the likelihood of repeated alliances. Beyond a certain point (about four alliances) this likelihood declines due to limited carrying capacity and fear of over dependence. Over time, the likelihood of repeated alliances increases (for the first 3.8 years), due to increasing mutual awareness, until the alliance ends and momentum declines due to short organizational memories and diminishing information.	Y
(Gulati & Gargiulo, 1999)	166 firms (7266 obs.)	Discussed	"A history of cooperation can become a unique source of information about the partner's capabilities and reliability and increases the probability of the two organizations forming new alliances with each other" (p 1446)	N
(Gulati & Singh, 1998)	1570 alliances	Discussed	"The idea of trust emerging from prior contact is based on the premise that through ongoing interaction, firms learn about each other and develop trust around norms of equity […] are concerned about potential sanctions, […] mitigate adverse selection problems" (p 799)	N
(Podolny, 1993)	2787 investment grade offerings	Examined[5]	"Superior information about an issuer due to prior transactions should allow the bank to underwrite an offering at a lower cost" (p 856) Prior transactions provide economic benefits, the effect of simultaneous transactions is not significant.	N
(Uzzi, 1999)	2266 firms' lending ties	Examined[6]	Over time, partners can learn about and share private information, develop trust and exploit opportunities for reciprocity. Both the duration of the relation (years) and the multiplexity (number of service ties) capture the same underlying construct and reduce costs of capital, but do not increase credit access (creditworthiness).	N
(Stuart, 2000)	150 firms (825 obs.)	Discussed	"Learning from another organization and then integrating that knowledge into a firm's own routines or technologies may take time. Similarly, it requires time for an alliance to lead to jointly-developed products and for a focal organization to gain access to a collaborator's customer base or entry into new market niches" (p 799).	N

[1] In Web of Science, we selected the 10 most-cited empirical studies that explicitly examine repeated (or prior) collaborations and cite the work of Granovetter (1985). We discern studies that discuss temporal processes of social embeddedness from studies that also empirically examined these processes.
[2] Product term of number of alliances and years.
[3] Separate terms for prior relations and development of ongoing relation over time.
[4] Separate terms for number of prior alliances and timing of repeated collaboration.
[5] Separate terms for number of prior transactions and presence of simultaneous transactions.
[6] Separate terms for number of service ties and years of tie duration.

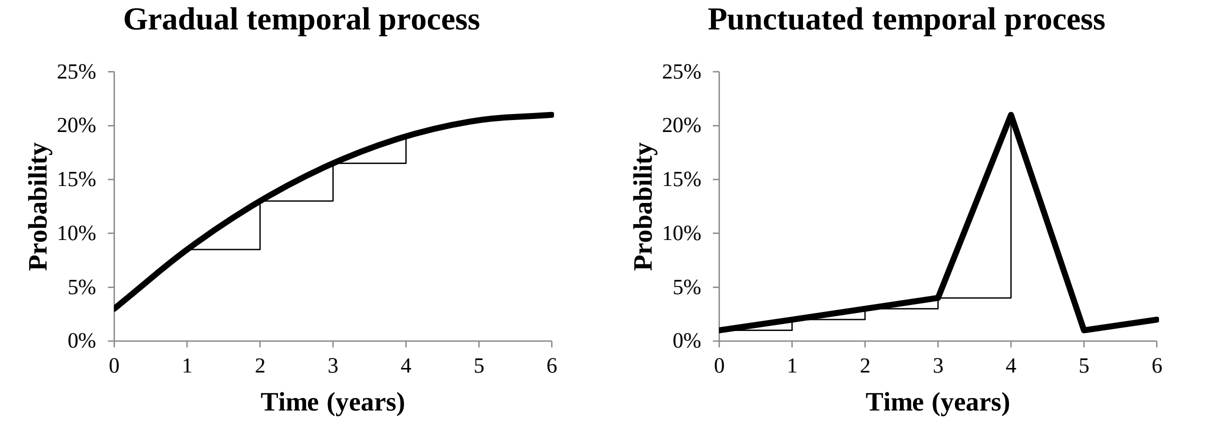
Gulati (1995b) initially hypothesized a (linear) decline over time in the likelihood of repeated collaboration, building on a repetitive momentum argument (Amburgey, Kelly, & Barnett, 1993). However, he reports the highest likelihood approximately 3.8 years after the start of the last joint alliance. He concludes that: "Information about another firm's reliability as a partner, its operations, and possible alliance opportunities becomes available *only once an alliance is in place*. Hence, *over time*, each firm acquires more information and builds greater confidence in the partnering firm. Concomitant with this process is an increase in the likelihood of a new alliance. […] this effect gives way to diminishing information *as past alliances end*, and the momentum for forming new alliances declines" (pp. 643-644, emphases added). In Gulati's study, this discrete point in time of alliance dissolution is not empirically examined, however.

In sum, we can conclude from our literature review that at present there is at a maximum one empirical answer to the question: when do organizations decide to repeat a collaboration? This lack of sound empirical foundations has strong implications for this study, as it is hard to proceed in a deductive manner. One powerful way to shed light on under-theorized phenomena is by presenting basic facts or descriptive statistics – in our study the distribution of the timing of repeated collaborations – and subsequently adding more sophisticated analyses to rule out some alternative explanations (Bettis, Gambardella, Helfat, & Mitchell, 2014). We therefore proceed in a more inductive fashion and develop some tentative arguments that provide a stylized reasoning to explain differentiated timing of repeated collaboration.

2.3.1 Two Temporal Lenses: Gradual versus Punctuated View

We follow the aforementioned literature in its use of an objective notion of time: as a generic resource that is available and used to perform tasks which is expressed in the amount of years. With respect to the temporal lens, most studies on social embeddedness confine themselves to a perspective on the progression of time as a gradual elapsing temporal process (e.g. Gulati, 1995b; Uzzi, 1999). We complement this perspective by adding another temporal lens, that of the progression of time as a punctuated temporal process. The temporal patterns of a gradual elapsing process and a punctuated process are shown in Figure 1. We refer to a gradual temporal process when the likelihood of repeated collaboration is decreasing or increasing gradually and relatively evenly over time (shown in the left-hand graph in Figure 1). A punctuated temporal process on the contrary occurs when a prolonged period of relatively gradual decrease or increase is interrupted by a short episode at which the likelihood of repeated collaboration fluctuates sharply over time (shown in the right-hand graph in Figure 1). In other words, the likelihood of repeated collaboration can gradually increase (gradual elapse), but can also be concentrated at a discrete point in time (punctuated), at for instance the consortium start, the midpoint, or the consortium end.

Figure 1: Gradual versus Punctuated Temporal Processes



Theoretically, it is important to note that a gradual temporal process comes with different meaning and modeling compared to a punctuated temporal process. In terms of meaning, a gradual process can, on the one hand, result in for instance a smooth curvilinear temporal pattern of the likelihood of repeated collaboration in a fixed time period, due to the stepwise replacement of the initial potential for learning and trust by fear-of-overdependence and information redundancy (Gulati, 1995a, 1995b; Uzzi, 1997; Uzzi & Spiro, 2005). A punctuated process on the other hand, alternates stable episodes with low prevalence of repeated collaborations with sudden sharp increases in the likelihood of repeated collaboration in a given time horizon, for instance due to the sudden urgency and awareness that arises at the midpoint (Gersick, 1991). In terms of modeling, the elapse of time in a gradual process is conceptualized by means of a continuous variable, while a punctuated process divides a time window up in episodes that are measured with dummy variables to conceptualize each point in time. Accordingly, we compare the traditional model that conceptualizes a gradual temporal process to a model that allows for more degrees of freedom (punctuated temporal process). Particularly central points in time like the start point, midpoint (Gersick, 1988) and endpoint (Gulati, 1995b) must be modelled in such a way, to separate consortium dynamics from post-consortium dynamics.

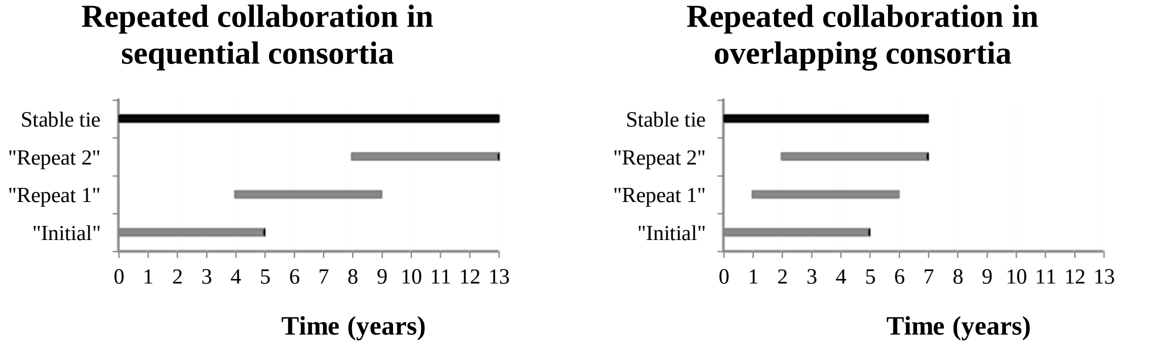
2.3.2 Sequential and Parallel Timing of Repeated Ties

On closer inspection, it turns out that Granovetter (1985) implicitly applies a gradual view in his embeddedness theory. Namely, Granovetter argued that social embeddedness is the result of *continuing relations* (including repeated collaboration) that economize on time, in which actors learn about the capabilities and trustworthiness of their partners and perceived opportunism declines (e.g. Gulati, 1995a; Parkhe, 1993; Stuart, 2000; Uzzi, 1999). Applying this implicit assumption in Granovetter's embeddedness theory to the collaboration in consortia, we would expect repeated collaboration to happen mainly around the end point of a consortium. Thus, repeated collaboration occurs in a sequential fashion, one starts a new joint consortium after the termination of another one. This by and large excludes the possibility of timing repeated collaboration in a parallel fashion in which joint consortia start closely after one another. We therefore would like to suggest a conceptualization of social embeddedness that includes both sequential and parallel timing of repeated collaboration.

Parallel timing of repeated collaborations within the time horizon of ongoing consortia pertains to an alternative view on the need to ramp up R&D activities quickly. This has implications beyond merely the repetition of an earlier collaboration. It also intensifies the collaboration, contingent on both the number of consortia started in parallel and the stage at which the repetition occurs. The earlier parallel consortia are initiated after the start of the initial joint consortium, the more overlap is organized in parallel consortia, and the higher the collaboration intensity. It is literally ramping up the volume of joint activities compressed within a limited amount of time.

Quite the opposite situation applies in case of sequential timing of repeated collaboration. In sequential joint consortia, all time available to the consortium until contract expiration is consumed before starting new consortia. Contrary to the parallel timing, in sequential timing the emphasis is on extending the duration of repeated collaboration. Figure 2 shows two distinct patterns of the timing of repeated collaboration: first sequential repeated collaboration, concentrated at the consortium end, resulting in the extension of the collaboration, and second parallel repeated collaboration, concentrated at the first year after the consortium start and resulting in overlapping consortia.

Figure 2: Timing of Repeated Collaboration



2.4 A Repeated Tie Taxonomy

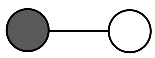
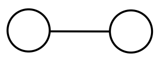
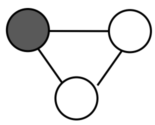
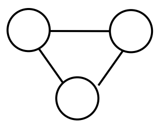
Why would timing of repeated collaboration be different? Previous research has shown that the timing of *new* collaborations is heterogeneous (Katila & Mang, 2003; Lavie, Lechner, & Singh, 2007) but the timing of *repeated* collaboration is virtually unexplored. We argue that partially this timing depends on the number, and type of partners involved with the consortium. Our reasoning combines research into science-industry collaboration, which revealed differences in time horizons and relationship intensity for science and industry partners (e.g. Balconi & Laboranti, 2006; Meyer-Krahmer & Schmoch, 1998; Niedergassel & Leker, 2011), with research that contrasts dyadic and multi-partner collaborations (e.g. Krackhardt, 1999; Madhavan, Gnyawali, & He, 2004; Simmel, 1950). We present a two dimensional repeated tie taxonomy that addresses the type of repeating actors (science versus industry dominated) and the number of actors (dyad versus multi-partner).

As repeated collaboration concerns the continuation of collaboration in two subsequent consortia at t_0 and t_n, *a repeating actor set* is constituted by those organizations that participate in successive consortia or in overlapping consortia. In this study, consortia consist of a university partner (consortium leader) and several industry partners. Because of the central role of the consortium leader with respect to the goal setting and orientation of the consortium, repeated participation of the consortium leader warrants the specific orientation of the repeating actor set. So when the same academic is consortium leader in two subsequent consortia we define that consortium as science dominated. Conversely, in case a set of industry partners repeatedly collaborates in two subsequent consortia with different consortium leaders, the orientation of the actor set is rather anchored by these industry partners, and therefore industry dominated. The dominance of either science or industry obviously prescribes partially the dominant institutional logic of a consortium (Balconi & Laboranti, 2006; Koka, Madhavan, & Prescott, 2006; Meyer-Krahmer & Schmoch, 1998).

The second axis of our repeated ties taxonomy relates to the number of repeating actors. Consortia consist of at minimum two, but can also include three or more partners (Krackhardt, 1999; Madhavan et al., 2004). So, repeated collaboration can be both dyadic or be a multi-party partnership. Simmel (1950) describes how collaboration between three actors can be fundamentally different from dyadic collaboration. The third actor can function as an arbiter, reducing risks of opportunism and withdrawal, because selfishness brings the risk to be outvoted by or isolated from the other group members. However, the presence of a third actor can come with costs, as the third can disrupt the intimacy of the relation between the other two, functioning as an annoying spectator. In addition, the third actor brings organizational complexities, making it more difficult to start a new consortium that covers the interests of all three actors. The distinction between dyads and triads is fundamental, as the addition of a fourth or fifth actor leads to minimal additional differences (Krackhardt, 1999; Obstfeld, 2005; Simmel, 1950). Therefore, we make a distinction between science and industry dominated repeated collaboration, as well as repeated collaboration between dyads and multiple partners.

The taxonomy is shown in Figure 3, including science and industry dominated dyadic and multi-partner repeated collaboration. Gray circles represent the (academic) consortium leader, white circles the industry partners (members). It is important to notice that the taxonomy only concerns the repeating actors and not the single-time (new or transient) consortium members, e.g. industry dominated repeated collaboration relates to two or more industry partners that participate in two consortia with different (non-repeating) academic consortium leaders. Therefore, the non-repeating actors are not included in the visualization. The taxonomy is further discussed below. Now the taxonomy is defined, we will attempt to address the question: How does the likelihood of repeated ties unfold over time, and to what extent is the timing of repeated ties different for distinct types of involved actor sets?

Figure 3: Actor Sets Involved in Repeated Collaboration

Dominant logic: Actor Set:	**Science dominated (same consortium leader)**	**Industry dominated (different consortium leader)**
Dyadic		
Multi-Partner		

2.5 Methodology

This chapter uses a longitudinal analysis of the establishment of 1715 multi-partner R&D consortia, in an observation period of 22 years (1983-2004). The consortia are part of an innovation funding scheme in the Netherlands which has been financed by the Dutch government since 1981 and is still ongoing. The consortia – the unit of analysis in this study – consist of an academic consortium leader and a member committee of industry representatives. We define the consortium as a self-propelling organizational form that unites and connects the member organizations (Das & Teng, 2002; Doz, Olk, & Ring, 2000; Evan, 1993). All consortia carry out publicly funded R&D projects, financed by one of the oldest Dutch Technology Programs that pursues R&D collaboration between university and industry. The consortium leaders had an affiliation to one of the Dutch Universities, mostly Technical Universities or Science Departments of General Research Universities, and were linked to a member committee consisting of representatives of industrial firms or service providers. The consortium leader is considered as unique representative of his/her university. The ties between the actors within the consortia concern collective consortium membership. The consortium leader and members meet at least twice a year, to evaluate the consortium progression. Repeated collaboration concerns the joint participation of the members of one consortium in a second consortium.

This research context provides a great opportunity to investigate the timing of repeated collaboration, because; (I) the consortia are funded only if the composition of consortia fits the minimum funding requirements needed to stimulate collaboration; (II) repeated collaboration is important in this context as research agendas are likely to exceed the boundaries of a single R&D consortium; (III) in contrast to earlier studies (e.g. Gulati, 1995b) both the consortium start and the consortium end are reported, allowing for fine-grained examination of the timing of repeated collaboration; (IV) available data on 1715 consortia over 22 years allows tracing the timing of repeated collaboration up to 10 years after the consortium start; and (V) variance in consortium composition allows examining distinct types of repeated collaboration. Although the participation of industry members is mandatory, the choice whom to select is not prescribed. Consequently, the consortia vary in consortium goal, number (on average 4 to 5) and type of members, duration, and application area. Accordingly, the academic consortium leader can repeat the collaboration with one or more of the industry partners in subsequent consortia. Alternatively, two or more of the industry partners can repeat their collaborations in consortia with *different* consortium leaders. These different types of repeated collaboration can come with different time horizon that motivate distinct timing of repeated collaborations.

Our data were derived from statutory annual evaluation reports including descriptions of the consortium goal, members, the consortium start and end, etc. Only approved applications are included in the dataset. Although assessments might come with heterogeneity, all applications are assessed on the same quality standards. The funding agency does not limit either the number or the timing of repeated collaborations. Projects without a member committee (154) were excluded from the dataset. Furthermore, we left-censored the data at 1983 (59 consortia excluded), because during the first years of the funding scheme repeated collaboration was virtually non-existent. We traced the timing of four different types of repeated collaboration up to 10 years after the consortium start (subsequently 11797; 8375; 12198 and 12110 observations).

In addition, we conducted 51 interviews with consortium leaders and members active in consortia in one sector, namely the Dutch water sector. The interview respondents are stratified sampled on actor type (consortium leader / member), subfield, consortium success and repeated collaboration experience. The respondents represent 80 of the 102 consortia in this sector and observation period. Some respondents have participated in multiple consortia and some consortia are represented by multiple respondents. A central question in the interviews was: "What are the advantages/disadvantages of either parallel or sequential collaboration in multiple consortia with the same partners?" All responses are coded and discussed in the results section.

2.5.1 Measures

Repeated Collaboration. Repeated collaboration is operationalized according to our taxonomy in four distinct types of repeated collaboration, as a function of two dimensions: science or industry dominated, and dyadic or multi-partner. We assessed the four different types of repeated collaboration – the four dependent variables of this study – with four different models. The dependent variables are binary: in a given year, repeated collaboration can occur (1), or not (0). For each year since the start of a focal consortium, we examined the occurrence of each type of repeated collaboration, that is the start of a subsequent consortium that includes (partially) the same set of actors as the focal consortium. For example, science dominated multi-partner repeated collaboration is observed in a given year, when three or more actors of the focal consortium, including the academic consortium leader, start a new consortium. Although organizations can participate in several subsequent or parallel consortia, only the first repeated collaboration (per type) is attributed to the focal consortium. A robustness test including all future repeats is discussed below.

Time and Timing. To assess the timing of repeated collaboration, we used an event history analysis (Singer & Willett, 2003) with time as predictor for the likelihood of repeated collaboration. The time measures we used in this study, comprise of three elements: the type of temporal process (gradual/punctuated), the time-window (e.g. the observation period as per the consortium start), and the time pattern (e.g. concentrated at the consortium start/end). As not many network studies provide models and measures to assess the timing of repeated collaborations we partially followed Gulati (1995b) for the gradual view and partially developed our own approach to operationalize the punctuated view.

For the gradual view, Gulati's measure of time rests on the assumption that the likelihood of repeated collaboration follows a gradual elapsing temporal process. Therefore, it is modeled by means of a continuous variable, $\text{TIME}_{\text{(CONSORTIUM START=0)}}$, in combination with the quadratic term TIME^2 that tests a potential curvilinear pattern. Accordingly, the measure covers a time window for repeating a collaboration as per the start of the consortium, and ends either at the end of the observation period, or at the moment of repeated collaboration occurrence. We used a 10 year moving time window as per the consortium start, because no relevant repeated collaboration occurred more than 10 years after the consortium start.

In order to examine the punctuated view, we introduce an alternative time measure to examine the extent that the likelihood of repeated collaboration follows a punctuated temporal process. This implies a prolonged period of relatively little change interrupted by a short episode at which the likelihood of repeated collaboration fluctuates sharply. The likelihood of repeated collaboration might concentrate at discrete points in time, like the consortium start, the midpoint, or the consortium end. A punctuated temporal process can best be explored by means of dummy variables. To represent these patterns adequately, our measure includes two separate time windows, one as per the start of the consortium TIME $_{(\text{CONSORTIUM START}=0)}$ and a second one as per the end of the consortium TIME $_{(\text{CONSORTIUM END}=0)}$. Herewith, we extend formerly used models by explicitly separating consortium dynamics throughout the consortium, from post-consortium dynamics after the consortium. The dynamics in both time windows can be represented by means of dummy variables (TIME $_{\text{YEAR X}}$), or by means of a combination of dummy variables in the first time window with a continuous variable in the second time window. For the first time window that represents consortium progression, no repeated collaboration is considered more than 5 years after the consortium start (formal restriction of the funding scheme). The two windows jointly cover a period of up to 10 years after the consortium start. The consortium end is the statistical reference point, thus for instance positive and statistically significant dummies for year 0 and 1 indicate timing of repeated collaboration concentrated around the consortium start.

Control Variables. In this study we controlled for variance that results from the application area (dummies), historical year of observation (dummies), and consortium size (continuous variable). We observed consortia in seven application areas, namely 'Instruments' (reference category), 'Electrical engineering', 'Medical technology', 'Life sciences', 'Chemistry', 'Mechanical engineering', and 'Civil engineering'[7]. The consortium categorization was conducted by two coders, and is based on the consortium description, and potential patents. The inter-coder reliability, calculated by means of Cohen's Kappa, is ca. 95%. Furthermore, the historical year of observation varies from 1983 to 2004 (reference category). As we estimate marginal effects based on all observations in this study, the reference category has no implications for our findings. Finally, to correct for non-independence of observations, we added a network autocorrelation term to the model (Leenders, 2002). Because the year observations are nested in consortia, we used a two-mode network autocorrelation term that includes an 'exposure term' and a 'measure of participation', in our study the consortium size (Fujimoto, Chou, & Valente, 2011).

[7] Results of a robustness tests with repeated collaboration restricted to the boundaries of the application area, excluding cross application area repeated collaborations, are similar to the initial model.

2.5.2 Modeling

We employ a longitudinal research design to investigate the likelihood of repeated collaboration over time. Discrete event history analysis is applied, because this technique provides the opportunity to investigate the timing of event occurrence (Singer & Willett, 2003). As the dependent variables of our study are binary – repeated collaboration can occur in a given year, or not – we employ a logistic regression transformation. The data has a panel structure with two sources of variation: within case variance (elapse of time, observation years) and between case variance (consortium size, application area). We use random effects to control for the nestedness of the error terms. Fixed effects are not applicable to nonrepeating event history models (Allison, 2009).

Separate models are used to explore the timing of the four types of repeated collaboration. For every type of repeated collaboration – dyadic or multi-partner, and science dominated or industry dominated - the timing of repeated collaboration is explored by means of two central equations. The first equation (Eq. 1) corresponds to measures in the previous literature (Gulati, 1995b) and conceptualizes a *gradual* temporal process that relates to a curvilinear change in the likelihood of repeated collaboration, including a continuous linear and quadratic term to conceptualize the elapse of time. The second equation (Eq. 2) conceptualizes a *punctuated* temporal process, including dummy variables during consortium progression ($\text{TIME}_{\text{YEAR X}}$) and a linear term after consortium termination to conceptualize the elapse of time. We take this approach because the literature on a punctuated temporal process concentrates on the elapse of time during consortium progression (e.g. Gersick, 1988), while after the consortium end a linear decline is expected due to declining momentum (Amburgey et al., 1993; Gulati, 1995b). Continuous variables are labeled by (C); and dummy variables by (D). We use a logistic regression transformation because of our binary dependent variable. Therefore, the likelihood of repeated collaboration is π ($\text{REPEATED COLLABORATION}^{\text{Type A}}$) = $e^Z / (1 + e^Z)$, with:

<u>Equation 1</u>: Z = a + (D) observation year + (D) application area + (C) consortium size + (C) network autocorrelation + **(C) TIME** $_{\textbf{(CONSORTIUM START=0)}}$ + **(C) TIME^2** $_{\textbf{(CONSORTIUM START=0)}}$ $+ v_i + \varepsilon_{it}$.

<u>Equation 2</u>: Z = a + (D) observation year + (D) application area + (C) consortium size + (C) network autocorrelation + **(D) TIME** $_{\textbf{YEAR 0}}$ + **(D) TIME** $_{\textbf{YEAR 1}}$ + **(D) TIME** $_{\textbf{YEAR 2}}$ + **(D) TIME** $_{\textbf{YEAR 3}}$ + **(D) TIME** $_{\textbf{YEAR 4}}$ + **(D) TIME** $_{\textbf{YEAR 5}}$ + **(C) TIME** $_{\textbf{(CONSORTIUM END=0)}}$ $+ v_i + \varepsilon_{it}$.

2.6 RESULTS

Table 2 shows the descriptive statistics and correlations of the consortium level data. The consortium level data serves as source data for the four transformed panel data sets, one for each dependent variable. Besides the above mentioned control variables we included the year of consortium start and the average consortium duration, which provides the data for the historical observation year and elapse of time until the consortium end, in the transformed panel data sets.

It turns out that the likelihood of distinct types of repeated collaborations varies significantly. The likelihood of industry dominated dyadic repeated collaboration (further on IDrc: 1009 out of 1715 consortia, 59%) is higher than the likelihood of subsequently science dominated dyadic repeated collaboration (SDrc: 375 consortia, 22%), science dominated multi-partner repeated collaboration (SMrc: 262 consortia, 15%), and industry dominated multi-partner repeated collaboration (IMrc: 369 consortia, 22%)[8]. The observed difference makes sense from a statistical point of view, as IDrc is the least constrained form of repeated collaboration (consortia include only one academic consortium leader but multiple industry members that can repeat their collaborations).

Table 3 shows, per type of repeated collaboration (SDrc; IDrc; SMrc; and IMrc), the random effects logistic regression models. To identify which temporal process fits the data best, the *gradual* temporal process or the *punctuated* temporal process, we tested Equation 1 (gradual: Model 2) and Equation 2 (punctuated: Model 3) against a baseline Model 1 (with intercept and control variables)[9]. The overall model fit is examined by means of log-likelihood ratio tests (Long & Freese, 2006). In addition, we used Akaike information criterion (AIC) for non-nested model comparison between Model 2 and 3. The results show that, for all four types of repeated collaboration, both Model 2 and 3 fit the data better (Chi^2) than the baseline Model 1. However, only for SDrc, the AIC score of Model 2 is lower (better) than Model 3. In addition, only for SDrc, Model 2 does not fit the data worse compared to the general model. Thus, for SDrc, the best fitting model is achieved with Model 2 that conceptualizes a curvilinear *gradual* temporal process (defined as 'Equation 1' in the methods section)[10]. For all other types of repeated collaboration (IDrc; SMrc; IMrc), the lowest AIC score and hence the best fit to the data is achieved with Model 3. This model ('Equation 2') conceptualizes a *punctuated* temporal

[8] The percentages do not add-up to 100% as we used different models to examine the different types of repeated collaboration: A single consortium can result in different types of repeated collaboration, but only if different subsets of the consortium members participate in different follow-up consortia. A single consortium cannot result twice in the same type of repeated collaboration, as it drops out of the dataset if the examined type of repeated collaboration is observed.

[9] In addition, we tested Model 2 and 3 against a general model including dummy variables for both time windows. The general model is not reported in Table 3, because of parsimony reasons.

[10] For SDrc, Model 2 also fits better than a model with one linear term TIME $_{\text{(CONSORTIUM START=0)}}$.

Table 2: Descriptive Statistics and Correlations

	Variables	Mean	S.D.	1	2	3	4
1	Industry dominated dyadic RC	0.588	0.492	1.000			
2	Industry dominated multi-partner RC	0.215	0.411	0.372***	1.000		
3	Science dominated dyadic RC	0.219	0.413	0.044†	-0.016	1.000	
4	Science dominated multi-partner RC	0.153	0.360	0.168***	0.164***	0.211***	1.000
5	Year Consortium Start	1994.437	6.231	-0.027	-0.020	-0.161***	-0.077**
6	Instruments	0.180	0.384	0.041†	0.002	0.053*	0.084***
7	Electrical Engineering	0.177	0.382	-0.012	0.021	-0.013	-0.010
8	Medical Technology	0.087	0.283	-0.060*	-0.067**	0.086***	0.046†
9	Life Sciences	0.228	0.420	-0.099***	-0.034	-0.079**	-0.092***
10	Chemistry	0.211	0.408	0.052*	-0.003	0.027	-0.029
11	Mechanical Engineering	0.057	0.231	0.041†	0.013	-0.044†	0.001
12	Civil Engineering	0.059	0.237	0.070**	0.096***	-0.032	0.037
13	Consortium Size	4.348	2.527	0.343***	0.370***	-0.042†	0.149***
14	Consortium Duration	4.541	1.377	0.039	0.090***	-0.027	0.046†

1715 Consortia; † $p < 0.100$; * $p < 0.050$; ** $p < 0.010$; *** $p < 0.001$.

Table 2: Descriptive Statistics and Correlations [Continued]

	5	6	7	8	9	10	11	12	13
5	1.000								
6	-0.038	1.000							
7	0.046†	-0.218***	1.000						
8	0.036	-0.145***	-0.144***	1.000					
9	0.066**	-0.255***	-0.252***	-0.168***	1.000				
10	-0.053*	-0.243***	-0.240***	-0.160***	-0.281***	1.000			
11	-0.046†	-0.115***	-0.114***	-0.076**	-0.133***	-0.127***	1.000		
12	-0.035	-0.118***	-0.117***	-0.078**	-0.137***	-0.130***	-0.062*	1.000	
13	0.195***	0.060*	0.033	-0.003	-0.138***	-0.058*	0.100***	0.101***	1.000
14	0.201***	0.022	0.054*	0.015	0.013	-0.060*	-0.025	-0.034	0.159***

1715 Consortia; † $p < 0.100$; * $p < 0.050$; ** $p < 0.010$; *** $p < 0.001$.

process (year dummies) during consortium progression and a gradual decline after consortium end[11].

Now, that the best fitting model – hence the temporal process – is defined for all four types of repeated collaboration, we subsequently discuss the distinct temporal patterns. For SDrc the temporal pattern is conceptualized by Model 2 ('Equation 1'). It turns out that the likelihood of SDrc increases with the elapse of time since the consortium start, until a threshold is reached at ca. 4.1 years, after which the likelihood of SDrc drops again. Thus, the highest likelihood of SDrc is observed close to the average consortium end at approximately 4.5 years. The average consortium end, however, does not indicate the exact end of an individual consortium. Therefore, we tested with Equation 2 whether the consortium end is an explicit benchmark for repeated collaboration. It turns out that this is the case for IDrc, SMrc, and IMrc,

[11] For IDrc, SMrc and IMrc, Model 3 also fits better than a model with two linear terms TIME $_{\text{(CONSORTIUM START=0)}}$ and TIME $_{\text{(CONSORTIUM END=0)}}$, and Model 3 does not fit significantly worse compared to the general model.

Table 3: Logistic Regression of Likelihood Repeated Collaboration

	Science dominated dyadic repeated collaboration (SDrc)			Industry dominated dyadic repeated collaboration (IDrc)		
	Model 1 Baseline	**Model 2 Equation 1**	**Model 3 Equation 2**	**Model 1 Baseline**	**Model 2 Equation 1**	**Model 3 Equation 2**
Intercept	-4.147***	-4.593***	-3.588***	-4.771***	-3.296***	-4.200***
	(0.323)	(0.909)	(0.415)	(0.290)	(0.314)	(0.282)
Consortium Size	0.004	0.004	0.001	0.404***	0.265***	0.293***
	(0.026)	(0.028)	(0.026)	(0.028)	(0.028)	(0.033)
Network Autocorrelation	1.974***	1.849**	1.677**	3.035***	2.297***	2.368***
	(0.468)	(0.616)	(0.524)	(0.279)	(0.242)	(0.265)
Intra-class correlation	0.240**	0.275	0.197	0.435***	0.126**	0.205***
	(0.077)	(0.302)	(0.253)	(0.032)	(0.061)	(0.076)
Time (Consortium start=0)		0.433**			-0.098	
		(0.164)			(0.069)	
Time^2		-0.053***			-0.017*	
		(0.012)			(0.008)	
Time year 0			-0.979*			0.517*
			(0.396)			(0.240)
Time year 1			-0.281			0.941***
			(0.313)			(0.182)
Time year 2			-0.185			0.448*
			(0.259)			(0.180)
Time year 3			-0.075			0.500**
			(0.225)			(0.187)
Time year 4			0.122			-0.141
			(0.241)			(0.289)
Time year 5			-0.277			0.196
			(0.448)			(0.443)
Time (Consortium end=0)			-0.243***			-0.244***
			(0.055)			(0.054)
Log Likelihood	-1563.763	-1540.309	-1538.368	-2549.283	-2511.578	-2496.769
df	29	31	36	31	33	38
Chi^2	84.120***	46.910***	50.790***	531.400***	75.410***	105.030***
AIC	3185.526	3142.617	3148.735	5160.567	5089.157	5069.538
N	11797	11797	11797	8375	8375	8375

Subsequently 11797 and 8375 observations on 1715 consortia; Controlled for application area and observation year; Standard errors in parenthesis; † $p < 0.100$; * $p < 0.050$; ** $p < 0.010$; *** $p < 0.001$.

but not for SDrc. The results for SDrc are similar to the findings of Gulati (1995b), both in terms of temporal process (gradual and not punctuated), and timing (Gulati observed the highest likelihood at ca. 3.8 years, against ca. 4.1 years in our study).

This shows that it is only SDrc that follows the ‘gradually’ elapsing temporal process that is discussed in ET research. The three other types of repeated collaboration that are explored in this study (IDrc; SMrc; IMrc), follow temporal patterns that differ significantly from the gradual temporal process. They rather comply with a punctuated temporal process, conceptualized by Model 3 (‘Equation 2’). A proper interpretation of the dummy variables in this equation requires the computation of marginal effects, as discussed below. With respect to the continuous variable TIME $_{\text{(CONSORTIUM END=0)}}$, all three models show a strong negative effect

Table 3: Logistic Regression of Likelihood Repeated Collaboration [Continued]

	Science dominated multi-partner repeated collaboration (SMrc)			Industry dominated multi-partner repeated collaboration (IMrc)		
	Model 1 Baseline	**Model 2 Equation 1**	**Model 3 Equation 2**	**Model 1 Baseline**	**Model 2 Equation 1**	**Model 3 Equation 2**
Intercept	-5.530***	-4.602***	-3.940***	-7.274***	-6.160***	-6.867***
	(0.438)	(0.890)	(0.553)	(0.512)	(0.812)	(1.119)
Consortium Size	0.203***	0.152**	0.143***	0.530***	0.443***	0.502***
	(0.034)	(0.045)	(0.039)	(0.049)	(0.066)	(0.131)
Network Autocorrelation	1.612†	1.201	1.041	3.524***	3.030***	3.023***
	(0.848)	(0.731)	(0.714)	(0.745)	(0.704)	(0.821)
Intra-class correlation	0.475***	0.178	0.141	0.593***	0.474***	0.565***
	(0.070)	(0.294)	(0.259)	(0.049)	(0.104)	(0.173)
Time (Consortium start=0)		0.261*			0.074	
		(0.124)			(0.113)	
Time^2		-0.049***			-0.023*	
		(0.012)			(0.011)	
Time year 0			-0.765*			-0.326
			(0.334)			(0.637)
Time year 1			0.056			0.580
			(0.254)			(0.362)
Time year 2			-0.615*			0.243
			(0.271)			(0.292)
Time year 3			-0.700*			-0.033
			(0.285)			(0.298)
Time year 4			-0.328			0.499
			(0.304)			(0.329)
Time year 5			-0.015			0.363
			(0.426)			(0.595)
Time (Consortium end=0)			-0.514***			-0.171*
			(0.081)			(0.069)
Log Likelihood	-1185.513	-1166.020	-1147.923	-1354.178	-1344.962	-1334.091
df	29	31	36	30	32	37
Chi^2	98.870***	38.990***	75.180***	347.860***	18.430***	40.170***
AIC	2429.027	2394.041	2367.845	2768.356	2753.924	2742.181
N	12198	12198	12198	12110	12110	12110

Subsequently 12198 and 12110 observations on 1715 consortia; Controlled for application area and observation year; Standard errors in parenthesis; † $p < 0.100$; * $p < 0.050$; ** $p < 0.010$; *** $p < 0.001$.

of the elapse of time after the consortium end. This indicates that during its existence, the consortium creates an opportunity space for repeated collaboration, since the likelihood of repeated collaboration strongly declines after the consortium end.

In logistic regression models, the estimated effects are affected by all variables in the model (Hoetker, 2007). This can become problematic when dummy variables are fixed to the mean. Therefore, we estimated the average marginal effects by means of the observed values for all variables in the model. To explore the timing of repeated collaboration, we applied Bonferroni adjusted post hoc tests, and estimated to what extent the predicted probability in a given year differed from the likelihood of repeated collaboration in the year of consortium start and of consortium end. The predicted probabilities based on the average marginal effects are visualized in Figure 4, as well as the 95% confidence interval. To allow for a proper comparison, all figures are based on time measures that conceptualize a *punctuated* temporal process (‘Equation 2’). It is important to note that the range on the y-axis varies for the different types of repeated collaboration, due to the variance in general likelihood of repeated collaboration (subsequently 22%, 59%, 15%, and 22% for SDrc, IDrc, SMrc, and IMrc). In addition, for all types of repeated collaboration, the likelihood per year looks relatively small, as the total likelihood is stretched over multiple years of observation.

The northwestern quadrant of Figure 4 shows that the likelihood of SDrc increases during the first year of consortium progression (from 1.4% to 2.7%), and gradually decreases after the consortium end (from 3.5% to 0.3% 10 years after the consortium end). The likelihood of SDrc is statistically significant lower ($p < 0.050$) at the consortium start (1.4%) than at the fourth year after the start (4.0%), the consortium end (3.5%) and the year after the consortium end (2.8%). Both Equation 1 and 2 (gradual and punctuated temporal process) point towards the same timing of SDrc, ca. 4 years after the consortium start. However, as discussed before, Equation 1 (gradual temporal process) provides more parsimonious results for SDrc, and fits the data better than Equation 2.

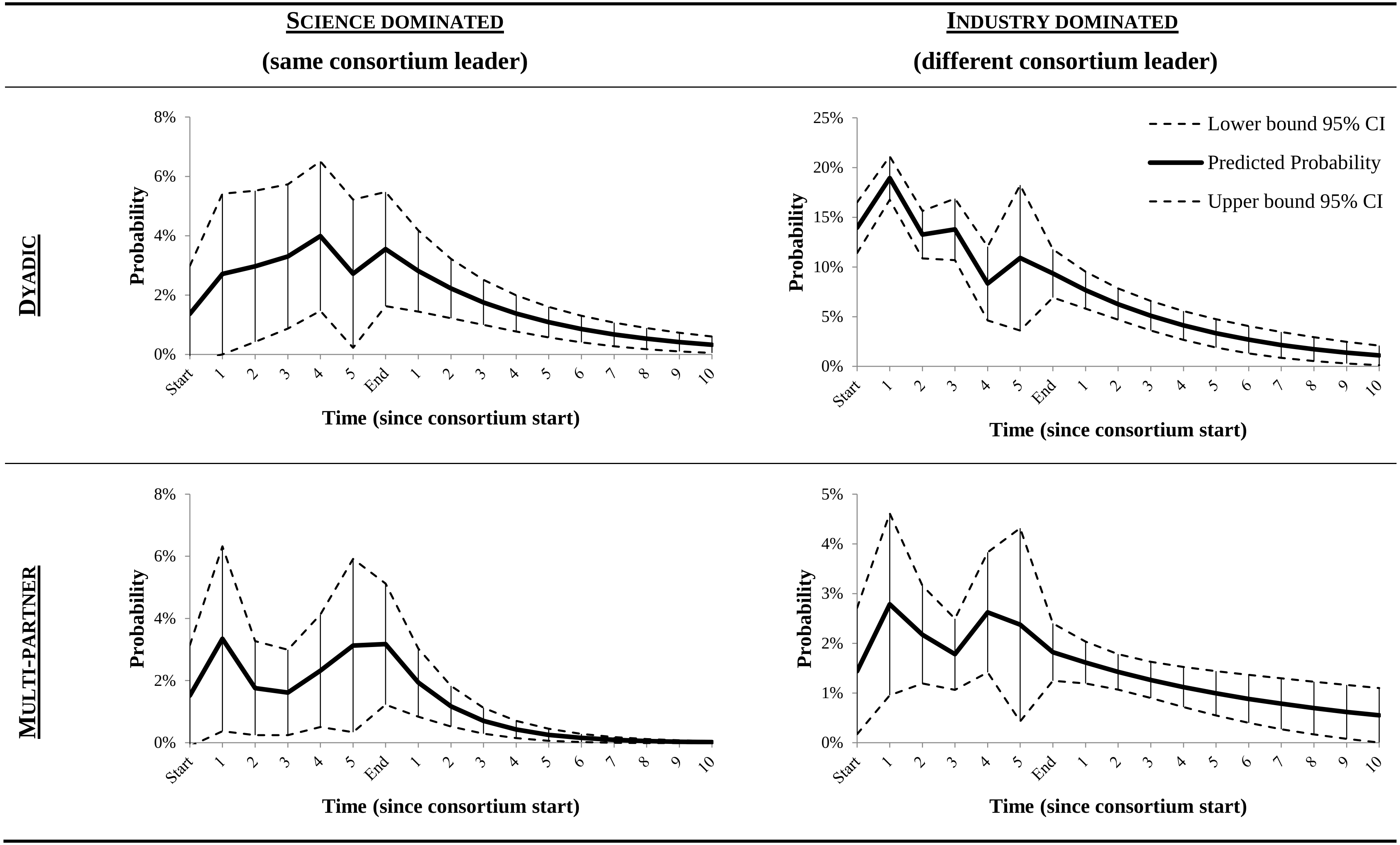
The northeast quadrant of Figure 4 shows that the likelihood of IDrc is highest the first year after the consortium start, and then declines over time. The first year after the start (18.9%) the likelihood of IDrc is statistically significant higher than at the consortium start (13.9%) and consortium end (9.3%).

The southwestern quadrant of Figure 4 shows that the likelihood of SMrc follows a hyper-cyclic pattern with two peaks, one the year after the consortium start and one at the consortium end, with a dip in between the peaks. The likelihood of SMrc is statistically significant lower at the consortium start (1.5%) than at the consortium end (3.2%), while the first year after the consortium start (3.3%), the likelihood is similar to the likelihood at the consortium end.

The southeast quadrant of Figure 4 shows that the likelihood of IMrc follows a pattern with two peaks, comparable to the pattern of SMrc. However, only the peak at the year after the consortium start (2.8%) is statistically significant higher than the likelihood in the year of the consortium start (1.4%) and consortium end (1.8%).

To compare the patterns across the models, we included all four types of repeated collaboration in one model with the type of repeated collaboration as ‘nesting factor’. In the next step, we computed the marginal effects nested in the type of repeated collaboration. To exclude differences in error variances across types of repeated collaboration (Hoetker, 2007), we compute the ratio of the ‘likelihood of a certain type of repeated collaboration at a given

Figure 4: Observed Time Patterns Repeated Collaboration (Average Marginal Effects)



Subsequently 11797; 8375; 12198; 12110 observations on 1715 consortia.

point in time / the overall likelihood of repeated collaboration for this type of repeated collaboration'. Finally, we made pairwise comparisons per two types of repeated collaboration per year. The comparisons are made with Bonferroni adjusted post hoc tests and are modelled per year, including the ratios of all four types of repeated collaboration, and per two types of repeated collaboration, including all years.

Our results confirm that, at the year of the consortium start and the subsequent year, the ratios of IDrc (respectively 1.0 and 1.6) and IMrc (1.1 and 1.8) are statistically significant *higher* compared to the ratios of SDrc (0.5 and 1.0), but not significantly different from the ratios of SMrc (0.7 and 1.8). At the year of the consortium end and the subsequent year, the ratios of IDrc (respectively 0.9 and 0.7) and IMrc (0.9 and 0.7) are statistically significant *lower* compared to the ratios of both SDrc (1.5 and 1.2) and SMrc (also 1.9 and 1.2). For SMrc both the peak at the year after the consortium start – corresponding to IDrc and IMrc – and the peak at the consortium end – corresponding to SDrc – are united in a hyper-cyclic pattern with two peaks.

2.6.1 Robustness Tests

First, we conducted a robustness test to rule out potential sample selection bias (Heckman, 1979), due to the exclusion of consortia without members (154). The sampling was instrumented as a function of the consortium leader's prior experience. Second, to test for a potential modeling bias of the nonrecurring event history model – only based on the first repeated collaboration – we applied a recurring event history model, including all future repeated collaborations. In both robustness tests, all temporal patterns remained unchanged, except for IMrc which became more similar to the pattern of IDrc. This finding confirms the conclusion that the hyper-cyclic pattern with two peaks mainly applies to SMrc.

Second, we conducted two robustness tests with subsequently the consortium success (Schwab & Miner, 2008) and embeddedness (Gulati & Gargiulo, 1999) as potential antecedents of repeated collaboration. Both did not affect the temporal patterns of science dominated repeated collaboration. For industry dominated repeated collaboration, after controlling for embeddedness, the peak at year one converged to the consortium start.

Third, to rule out the alternative explanation that academic consortium leaders postpone repeated collaboration to the consortium end, due to "scarcity of time", we demonstrated that during the focal consortium, leaders do invest time in *new* consortia with new partners. Conversely, the probability that an industry partner 'goes on an adventure' without the scientist, either on its own, or with other industry partners, strongly declines with the consortium progression, indicating the industry partner's increasing commitments to the consortium leader.

One exception is the year before the consortium ends, when scientists do seem to be occupied and industry partners withdraw.

Finally, we conducted separate analyses for multi-partner repeated collaboration with three (*triads*), four (*tetrads*) and five (*pentads*) members. Although the proportion of triads respectively tetrads is greater than that of pentads, all follow the same pattern, confirming the plausibility of third-party effects (Simmel, 1950) as explanatory mechanism.

2.6.2 Interview Results

Previous research has shown that interaction frequency and duration are two distinct dimensions of social embeddedness (Marsden & Campbell, 1984, 2012; Mathews et al., 1998). Likewise, we examined the distinctiveness between sequential and parallel timing of repeated collaboration as dimensions of social embeddedness. For this purpose, we asked 51 interview respondents (13 consortium leaders and 38 members), active in consortia in the Dutch water sector[12], about their motives for either sequential or parallel timing of repeated collaboration.

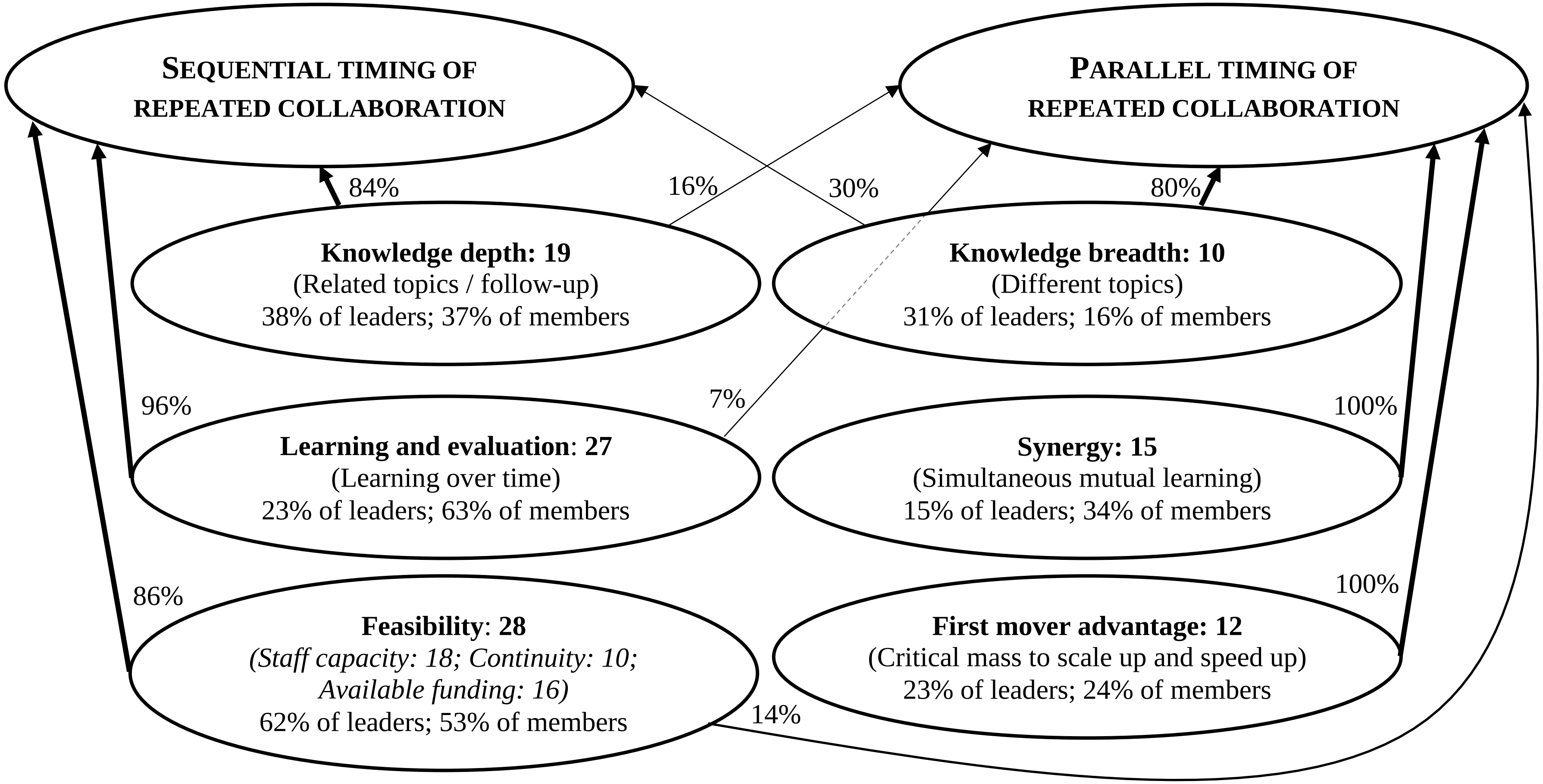
One exemplary response from a consortium member was: “Both have their advantages. If you are doing things at the same time, then you can broaden the scope and address multiple types of questions. And if you do the one after the other, then you particularly look at what has been learned and how to continue with new questions that have emerged”. All responses are coded and shown in Figure 5. Six motives are identified that respondents linked to either sequential or parallel timing. Bold numbers represent the number of respondents that mentioned a specific motive, indicating the relevance of a concept. In addition, Figure 5 includes the percentage of the 13 consortium leaders and 38 members that gave this response. Furthermore, the arrows in Figure 5 relate the six motives to the two timing strategies, the percentages next to the arrows show to what extent a specific response was associated with either sequential or parallel timing of repeated collaboration.[13]

The results show that sequential and parallel timing of repeated collaboration are distinct dimensions of social embeddedness. Whereas sequential timing is associated with deepening knowledge in one research line by means of follow-up projects, parallel timing is mainly associated with knowledge breadth, with separate research lines. Furthermore, sequential timing is associated with learning and evaluation over time. Particularly consortium members want to evaluate before repeating the collaboration with the same consortium leader. Parallel timing on the other hand, is exclusively associated with synergy (simultaneous cross-consortium learning) and with first mover advantages (critical mass to scale up and speed up).

[12] Consortia in the water sector cover various application areas, including Instruments, Civil Engineering, and Chemistry.

[13] The percentages per concept do not always add up to 100%, because some respondents associated a given concept both with sequential and parallel timing of repeated collaboration, or with none of them.

Figure 5: Parallel versus Sequential Timing of Repeated Collaboration – Interview Results



51 interviews with 13 consortium leaders and consortium 38 members.

Finally, sequential timing is associated with feasibility; i.e. the ability to participate in a consortium, in terms of staff capacity, available funding and demand for continuity. Obviously, both academic consortium leaders and consortium members (industry representatives) define sequential and parallel repeated collaborations as distinct concept that serve different goals.

2.7 TOWARD A PRELIMINARY THEORY OF THE TIMING OF REPEATED TIES

In this research, we explored how the likelihood of repeated collaboration unfolds over time, and to what extent the timing of repeated collaboration is associated with distinct actor sets involved in the R&D consortia. We derive the baseline assumptions from Embeddedness Theory (ET), more specifically Granovetter's (1985) notion of the social embeddedness of economic action. In ET it is argued that, over time *continuing relations* (including repeated collaboration) result in social embeddedness (1985), in which trust is developed, perceived opportunism declines, and actors learn about their partner's capabilities (e.g. Gulati, 1995a; Parkhe, 1993; Stuart, 2000; Uzzi, 1999). These learning and evaluation processes gradually unfold over time, and wear off, as information over partners eventually will be saturated. As a consequence, the likelihood of repeated collaboration increases, up to a certain limit, after which declining momentum, information saturation, and fears of over-dependency reduce the likelihood of repeated collaboration (Gulati, 1995b; Uzzi, 1997; Uzzi & Spiro, 2005). This reasoning in ET research assumes a preference for sequential timing of repeated collaboration: a new consortium is most likely to get started near the end of a preceding consortium.

We extended ET and explored the timing of four different types of repeated collaboration, by means of a database including the establishment of 1715 Dutch R&D consortia over a time period of 22 years. We observed the highest likelihood of repeated collaboration at *two* points in time: Closely after the consortium start (parallel timing of repeated collaboration) and near the consortium end (sequential timing of repeated collaboration). Contrary to the implicit assumption used so far in ET our finding implies that:

Proposition 1: Timing of repeated collaboration is heterogeneous.

However, this observation does not invalidate Granovetter's (1985) general assumption that social embeddedness is created through continuing relations, which requires sequential repeated collaboration. We did observe the assumed sequential timing of repeated collaboration (Granovetter, 1985; Gulati, 1995b), but only for one specific type of repeated ties, namely science dominated dyadic repeated collaboration. For the other types of repeated collaboration the timing followed a different pattern. We argue that the "ripening" of the relationship and development of goodwill trust (Newell & Swan, 2000) is an important micro-process to explain the sequential timing of repeated collaboration. As an alternative explanation, one could argue that this finding might be due to the limited carrying capacity of the consortium leader. Since time and resources of the consortium leader are limited, it is more likely that a new consortium is only set up once the prior one is finished and hence, we would expect consortium leaders to primarily engage in sequential repeats. We ruled out this alternative explanation by conducting a robustness test.

We demonstrated in this study, that sequential timing of repeated collaboration only applied to one type of repeated ties while the other three types followed other patterns. For sequential timing of repeated collaboration, ET research provides a rather generic explanation, namely learning and evaluation processes over time. However, in case learning and evaluation processes are seen as the main explanation for sequential repeated collaboration, the occurrence of parallel timing of collaboration is hard to explain, because actors first need time to learn and evaluate. It is even more striking that parallel timing does not only occur, but that the proportion of parallel repeated ties by far exceeds the proportion of sequential repeated ties (76% vs. 24%), which calls for a different explanation. We therefore argue that partially the timing depends on the institutional logic the consortium members mainly adhere to and the number of partners involved in the consortium, which we will subsequently discuss.

In our case, industry partners are embedded in a different institutional logic compared to university partners that makes for distinct time horizons within which R&D is supposed to deliver outcomes. Whereas university partners often use time horizons for learning and goal completion that fit the time they generally have available to finish PhD projects (Balconi & Laboranti, 2006; Meyer-Krahmer & Schmoch, 1998; Niedergassel & Leker, 2011), industry partners face pressures to early responses due to rivalry and time to market dynamics (e.g. Chen, Reilly, & Lynn, 2012; Khanna, 1998). The initial information gathered once the consortium is in place (Gulati, 1995b; Zaheer et al., 1999) provides a justification for industry partners to repeat early, in order to provide quick wins and opportunities to spread risks. Given that time required to build experience based (goodwill) trust (Zaheer et al., 1999), is lacking in case of industry repeats, these actors must rely on 'quickly gained' competence trust (Newell & Swan, 2000). The institutional logics argument derives its plausibility from the congruence across different models of particularly industry dominated repeated collaboration. Therefore, we state that:

Proposition 2: Institutional logics affect the timing of repeated collaboration: (a) in case of a science logic, actors are more likely to pursue sequential timing of repeated collaboration, whereas (b) in case of an industry logic, actors are more likely to pursue parallel timing of repeated collaboration.

A second explanation for the difference in timing relates to the number of repeating actors. For the timing of dyadic repeated collaborations, the institutional logics arguments provide a sound explanation. But in multi-partner repeated collaboration, both parallel and sequential timing of repeated collaboration are combined, particularly when the repeating actor set includes both academic and industry partners.

The distinction between dyadic and multi-partner repeated collaboration is based on Simmel's (1950) notion of the third actor as potential arbiter, reducing risks of opportunism, mediating conflict, and enhancing trustworthiness. Accordingly, the inclusion of a third party might allow both parties to overcome their relational risks and to adhere to the demands both for relational intensification and the extension of the relationship duration. While relational intensification falls more into an industry logic in order to scale up and speed up innovation, a science logic rather asks for an extension of the relationship duration and long-term commitments. At the same time, organizational complexities and limited opportunities for collective interactions (Krackhardt, 1999; Madhavan et al., 2004), might restrict opportunities for multi-partner repeated collaboration to the consortium start, where actors first meet, and the consortium end, where actors evaluate consortium outcomes. The distinction between dyads and triads is fundamental, whereas the addition of a fourth or fifth actor leads to marginal differences (Krackhardt, 1999; Obstfeld, 2005; Simmel, 1950). The Simmelian argument is confirmed by means of different robustness tests that show identical temporal patterns for repeated collaborations with three, four and five members. Therefore we state that:

> *Proposition 3: In multi-partner repeated collaborations, the prevalence of parallel and sequential timing of repeated collaboration is equal, and hence, the effect of institutional logics is nullified.*

In order to explore whether the timing differences also relate to distinct sociological phenomena (Marsden & Campbell, 1984, 2012; Mathews et al., 1998), we conducted 51 interview, with 13 consortium leaders and 38 members. Results point towards two distinct "time utilization strategies" – the *time compression strategy* and *time extension strategy* – that are associated with different motives.

A time compression strategy, which is reflected in parallel repeated collaborations, signals the urgency of a research objective that motivates to ramp up efforts quickly or capitalize on new opportunities. Such a timing of repeated collaboration does not at all fit the 'getting to know, create a safe, trustworthy environment' kind of argument of ET (e.g. Granovetter, 1985; Gulati, 1995b). In those consortia critical mass is pursued, and momentum is chosen to solve a complex task in as short a time as possible. This approach typically applies in an industry context in which first mover advantages and time to market are core strategic issues. Whereas parallel timing is associated with compression of activities in the shortest possible time frame, a time extension strategy, reflected in sequential timing, is more like organic maturation of knowledge and competences, by spreading out activities over an increasingly longer time horizon, with the extension of the relationship duration. Therefore, unlike for the time compression strategy, ET arguments do apply for the time extension strategy. As a consequence, we state that:

> *Proposition 4: Heterogeneity in timing of repeated collaboration is associated with differentiated time utilization strategies: (a) a time compression strategy - parallel timing of repeated collaboration - is associated with gaining knowledge breadth, synergy and first mover advantages, whereas (b) a time extension strategy - sequential timing of repeated collaboration - is associated with gaining knowledge depth, learning and evaluation over time as well as feasibility.*

Exploring the variance in the timing of different types of repeated collaborations represents the main scientific contribution of this chapter. We thus extend embeddedness theory as developed by Granovetter (1985) with a temporal perspective. The variance of timing of repeated collaborations indicates the underlying possibility for actors to make conscious choices with regard to developing their relationships. We therefore combine Granovetter's original approach with regard to structure and agency in ET with Emirbayer and Mische's (1998) perspective how agency takes place in a specific temporal-relational context. On the micro-level, this combination enabled us to demonstrate how actors attempt to shape and modify their own relational context over time. This insight is crucial in understanding how micro-level choices about collaboration lead to macro level network dynamics at the field level (Ahuja, Soda, & Zaheer, 2012). Parallel timing of repeated collaborations enhances the connectedness of the network, since the ties become embedded in multiple simultaneous collaborations. Sequential repeated collaboration on the other hand provides stability to the network, since the collaboration is continued over multiple years keeping actors within the network. We observed that multi-partner repeated collaboration has the potential to combine parallel and sequential timing of repeated collaborations and thus combine both connectedness and stability. We suggest that this specific combination of timing strategies can lead to a stable core within a network. This stable core consists of actors that collaborate repeatedly and intensively and thus form the backbone of the network where knowledge is accumulated, but also functions as a magnet for new entrants. This combination of a stable core and flexible shell of new entrants in turn can lead to both a continuity of knowledge accumulation and a gradual renewal of the knowledge base.

The main practical implication is that our study reveals strong differences in temporal demands of science and industry partners. For consortium members and consortium leaders it is important to address this tension in order to increase the likelihood that the relationship is maintained in the long run. The study shows that, one way to overcome this pitfall and to satisfy both science and industry demands, is to opt for multi-partner repeated collaborations instead of dyadic repeated collaborations. In this way, conflicting demands for short-term intensification and long-term stability become united in the consortium as a social entity.

One of the main scientific implications of this study is that social embeddedness should not only be measured with the number of repeated collaborations, but also include their timing. Otherwise, findings might lead to inaccurate or even flawed conclusions. We therefore call for a broader diffusion of this practice that further extends the work that already included both time and number of repeated collaborations (e.g. Gulati, 1995b; Uzzi, 1999).

This study has three central limitations. First, due to the fact that the likelihood of repeated collaboration is stretched over multiple years of observation, the observed effect sizes are quite small and 95% confidence intervals relatively wide. However, post hoc tests show that average marginal effects differ, both within and across types of repeated collaboration. We therefore are confident that the observed patterns are empirically valid.

Second, the data used in the main analysis is relatively abstract and does not contain any information about the substantive processes underlying the observed patterns. Even though we conducted additional qualitative interviews to validate our findings, future research should investigate the underlying processes in more detail.

Third, we studied social embeddedness in a very specific empirical setting in which organizations collaborate in time bound research consortia to achieve formally stated goals. This setting allowed us to test the different temporal patterns of repeated collaboration. At the same time, future research has to validate these findings in other contexts and with other types of social actors.

This research supports the importance of a temporal perspective on inter-organizational collaboration, as called for by several researchers (Ahuja et al., 2012; Ancona et al., 2001; Zaheer et al., 1999). We would like to reemphasize this call and suggest the following directions for future research. Our study has demonstrated that repeated collaboration can reflect very different time utilization strategies. Future research should examine the performance implications of the different strategies. In addition, variance in the timing of repeated collaboration is not only indicative for different relational processes, but also adds up to different network structures (e.g. Moody, 2002; Rawlings, McFarland, Dahlander, & Wang, 2015). We therefore call for research that examines network level consequences of the timing of collaborations. Finally, our research has demonstrated that distinct time utilization strategies of individual organizations can converge in consortia. Future research should extend this research line, and explore the functioning and evolution of social networks with different modes. We are convinced that such a research agenda would both contribute to and fruitfully combine the increasing research on network dynamics and a further development of embeddedness theory. This we believe is an exciting perspective both for sociological research as a whole and for research on social networks in particular.

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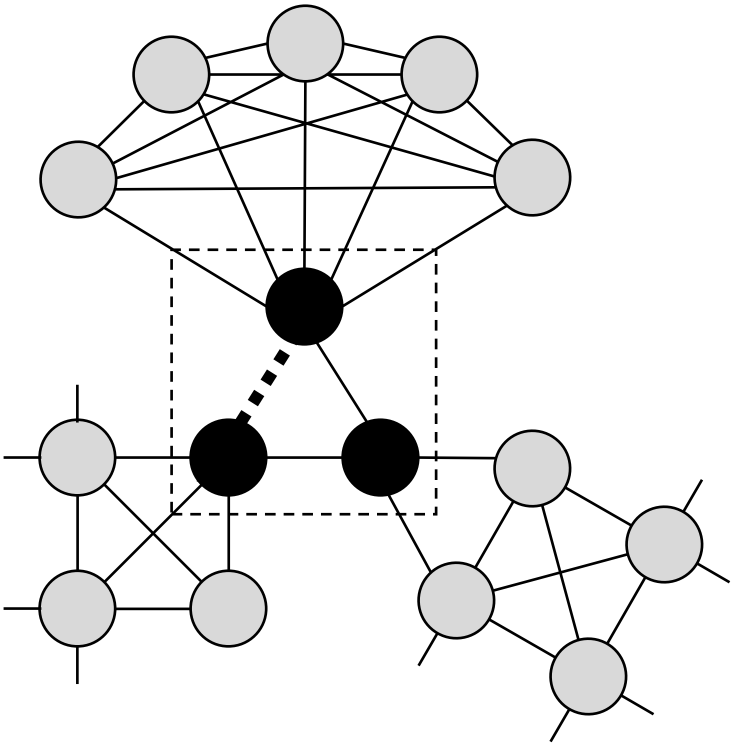
CHAPTER 3

TOWARDS A TIME-SENSITIVE THEORY OF EMBEDDEDNESS: APPLYING A TEMPORAL PERSPECTIVE ON THE DUALITY OF ORGANIZATIONS AND R&D CONSORTIA



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ABSTRACT

This chapter examines the temporal dynamic effects of past embeddedness on the likelihood of formation and repetition of inter-organizational relations through R&D consortia. First, we conduct a literature review and an analysis of 51 interviews with leaders and members of R&D consortia in order to develop hypotheses. Second, we test those hypotheses by means of a longitudinal analysis on the formation and the repetition of 7346 ties between consortium leaders and consortium members in 1715 multi-partner R&D consortia, in an observation period of 22 years. Results show that all investigated effects of past embeddedness are temporal dynamic: i.e. they change over time for different stages of a consortium. A consortium serves as social structure that embeds a newly formed dyad and modifies the effects of past embeddedness on the formation and repetition of ties. Simultaneously, a consortium acts as social entity that becomes embedded in the wider inter-organizational network. We contribute to a temporal perspective on embeddedness theory by showing differential effects of past embeddedness on tie formation and repetition.

A previous version of this chapter was published in *Academy of Management Proceedings* (Vol. 2012, No. 1) as Mannak, R.S., Raab, J., & Smith, A.C. (2012). Repeated Ties in Multi-Partner R&D-consortia: Temporal Dynamic Effects of Embeddedness. Previous versions of this chapter were presented at the 2012 Annual Meeting of the Academy of Management (Boston, 2012), and the 31th EGOS colloquium (Athens, 2015).

3.1 INTRODUCTION

When performing complex tasks like R&D, organizations increasingly depend on inter-organizational collaboration through R&D consortia, in order to access complementary resources and assets, to reduce production cycles and time to market, and to forego risks associated with 'going it alone' (e.g. Doz & Hamel, 1998; W. W. Powell, Koput, & Smith-Doerr, 1996; Schilling & Phelps, 2007). Achieving these much wanted gains makes the decision *with whom and when* to collaborate a vital aspect of the network strategies of organizations. In this chapter, we ask whether the formation of dyads and the repetition of dyads between a consortium leader and a member are impacted differentially by their past embeddedness. Past embeddedness captures the information and experience acquired with past collaborations and largely informs the decision on whether to repeat a relation. Repeated collaboration in this study is the continuation of a collaboration between a consortium leader and a member through a second consortium.

According to embeddedness theory, the decision with whom and when to collaborate is enabled and constrained by embeddedness in social relations (Granovetter, 1985; Gulati & Gargiulo, 1999). Embeddedness theory, however, does not distinguish between embeddedness effects on tie formation and on repeating existing ties. Therefore, it is implicitly assumed that effects of past embeddedness are stable over time, more specifically that effects of past embeddedness are equally strong for tie formation, and for repeating ties.

Moreover, the temporal dynamics of dyads becoming part of a larger social structure, like a triad or a complete network, received considerable attention in the literature (e.g. Ahuja, Soda, & Zaheer, 2012; Gulati & Gargiulo, 1999; Walter W. Powell, White, Koput, & Jason, 2005). However, this does not fully capture the fact that embeddedness of this new social entity, in our case the R&D consortium, has a separate effect on the repetition of dyads. Consortium embeddedness refers to the extent to which the consortium, in which the dyad is nested, in turn becomes embedded in the wider network. To the best of our knowledge, this particular type of embeddedness – consortium embeddedness that is - has not been studied so far, and calls for temporally dynamic models. In this chapter, we introduce a time-sensitive theory of embeddedness that challenges the assumption of a stable effect of embeddedness and simultaneously takes into account the effects of actors being nested in larger social entities. We further demonstrate in this study that the temporal dynamics and the nestedness of actors and their ties are not only two reasons to extend embeddedness theory, but are in fact closely interlinked in explaining tie formation and repetition.

We thus first compare the effects of past embeddedness on the likelihood of tie formation and repetition at distinct points in time, that is: a) when the dyad is formed; b) when the repeat of any tie occurs briefly after the tie formation; c) when the repeat of any former tie occurs after tie termination. This comparison allows us to answer questions about the enabling and constraining effects of past embeddedness over time, and helps in revealing the workings of the information and experience gained from past collaborations. Do effects of some types of past embeddedness last longer, whereas others decay faster, relative to each other? In our research setting, dyads are always formed through R&D consortia, thus the formation and termination of the consortium are the two central events in our model that can give new meaning to past embeddedness. We examine the extent to which effects of past embeddedness on tie formation and on repeating dyads get modified, i.e. are temporal dynamic, because of the dyad becoming embedded in the R&D consortium and the consortium becoming embedded in the wider network. A temporal dynamic effect in our context means that the effect is not stable over time, in particular, that the effect of past embeddedness on the likelihood of tie formation is not equal to the effect on the likelihood of repeated collaboration.

Second, we address the temporality of past embeddedness on repeated dyads by extending the existing typology of embeddedness. Next to relational, structural, and positional embeddedness (Gulati & Gargiulo, 1999; Uzzi, 1997), we introduce a novel concept: consortium embeddedness. Consortium embeddedness is defined as the position of a consortium in its network and captures the temporal dimension of the (co-)evolution of dyads after becoming part of an R&D consortium. It directly represents the way in which the consortium pulls together the experiences and routines of its participants and provides access to external resources, i.e. the consortium creates a new relationship between its participants and its surroundings. Over time the dyads will be embedded on the one hand in their past relationships, but besides that the tie is also embedded in the newly formed consortium. The consortium serves both as social structure or context for the involved agents (Breiger, 1974) and as an additional social entity from which the dyad can draw resources, status, reputation, visibility etcetera, but which also imposes constraints and restraints, and new relational risks (Das & Teng, 2002a). As time moves on, neither the involved agents themselves nor their relations remain the same, as they are exposed to new conditions derived from the R&D consortium’s embeddedness. For example, if dyads get surrounded with new consortium partners with high status, prominent engineers with highly central positions in their respective networks, relations co-evolve and are revisited, former routines might be revised, accumulated experience might turn out to be futile, or even more valuable than thought before, due to the new competencies brought in that simultaneously make for new ways of evaluating and monitoring activities, and their outcomes. As a consequence the social entities – nodes – that forged the dyads co-evolve in the social setting of the consortium in which they perform their joint R&D. This co-evolution in turn affects the likelihood of repetition of ties. This implies that embeddedness is not static, but transforms as well over time. As time progresses the consortium starts to act as a novel social entity for the dyads that has its own embeddedness and that potentially impacts on the likelihood of repeated dyads at different time points. In sum, a temporal perspective on embeddedness calls for alternative dynamic models of past embeddedness, as well as for an expansion of the existing embeddedness typology. In case of actors being nested in a larger social entity, the embeddedness of this entity in the wider network has to be taken into account. In this study we refer to this fact as *consortium embeddedness*. Summarizing these conceptual arguments leads to the following research question: *To what extent is the likelihood of present tie formation and future repeated collaboration between a consortium leader and a consortium member related to the temporal dynamic effects of past embeddedness in a network of organizations and consortia?*

In order to answer the research question, we first review the embeddedness literature using a temporal lens and conduct an analysis of 51 interviews with consortium leaders and consortium members. Based on this exploration, we formulate hypotheses which we subsequently test by means of longitudinal data of the formation and the repetition of 7346 ties between consortium leaders and consortium members in 1715 multi-partner R&D consortia, in an observation period of 22 years. We apply a Heckman (1979) selection model to investigate the likelihood that a consortium leader and consortium member first *form* a dyad in a new R&D consortium (stage one), and second, *repeat* their initial collaboration (stage two), as a function of different types of embeddedness. In addition, we discern the *timing* of repeated collaboration either during or after the joint R&D consortium.

Our contribution to embeddedness theory is two-fold. Firstly, the study responds to previous calls for time-sensitive theories of collaboration (e.g. Ancona, Goodman, Lawrence, & Tushman, 2001; Zaheer, Albert, & Zaheer, 1999). We replicate and extend the work of Granovetter (1985) and Gulati and Gargiulo (1999), and introduce a time-sensitive theory of embeddedness by developing a dynamic model that provides understanding of the temporal dynamic effects of embeddedness on the formation and repetition of ties. In this way, the study differentiates between an embeddedness theory of tie formation and an embeddedness theory of repeated collaboration. Secondly, the study adds consortium embeddedness to the existing embeddedness typology. We demonstrate the dual role of the consortium as social structure and as social entity (Breiger, 1974). The consortium as social structure or context embeds the newly formed dyad and provides a proximate frame of reference to the participating organizations. The consortium as social entity (Das & Teng, 2002a) has its own goals and resources and becomes embedded over time in the inter-organizational network that provides a distal frame of reference to the consortium members. The duality is that the consortium embeds a dyad between two organizations, and simultaneously the consortium gets embedded in the innovation network through the member organizations. The study therefore provides insights in the duality between the two social entities in an innovation network, organizations and consortia.

3.2 Theoretical Foundations of Embeddedness Theory

Granovetter (1985) has argued that the formation of economic relations between ego and potential alters is affected by their joint embeddedness in the structure of social relations. He discerns three sources of information about potential partners: direct information, indirect information and generalized information about someone's reputation. He states that: "Better than the statement that someone is known to be reliable [positional embeddedness] is information from a trusted informant that he has dealt with that individual and found him so [structural embeddedness]. Even better is information from one's own past dealings with that person [relational embeddedness]." (Granovetter, 1985, p. 490).

One widely adopted empirical elaboration of Granovetter's social embeddedness perspective is developed by Gulati and Gargiulo (1999). Gulati and Gargiulo defined three types of past embeddedness of inter-organizational relations: relational embeddedness (direct information that resides from prior direct ties between ego and alter); structural embeddedness (indirect information acquired through common partners); and positional embeddedness (generalized information from an advantageous position of alter and ego in the network). The explanation of past embeddedness effects on partnering as defined by Granovetter (1985) and Gulati and Gargiulo (1999) resides in the quality and reliability of the information made accessible by past collaboration. However, besides information advantages, Granovetter (1985) also pointed out embeddedness constraints, a topic somewhat neglected by Gulati and Gargiulo (1999). For instance prior agreements and obligations might limit future partnering opportunities (Coleman, 1988; S. X. Li & Rowley, 2002).

We elaborate these arguments by adding a temporal perspective and argue that positive, enabling and negative, constraining or restraining effects of social embeddedness occur at different points in time. Our reasoning partially builds on the recent work of Dahlander and McFarland (2013), and extends this new research line by demonstrating the dynamic effects of past embeddedness, either immediately with the consortium formation, or over time between the consortium formation and termination. Once the consortium is installed, past embeddedness effects might change for at least two reasons. First, the availability of firsthand information on the partner's capabilities and trustworthiness reduces the added value of indirect or generic information (Dahlander & McFarland, 2013; Granovetter, 1985; Polidoro, Ahuja, & Mitchell, 2011). Second, once the consortium is installed, the modus operandi is likely to change. Over time consortia develop a selection logic mainly driven by finding good partners (Gulati & Gargiulo, 1999), which is likely to be replaced by a joint value creation logic, targeted at output from the collaboration (Das & Teng, 2002b; Ring & Ven, 1994). Throughout this process from tie formation to repetition several mechanisms may be induced by past embeddedness varying from information exposure, to benefits such as resource complementarity, and restraints coming from mutual obligations (Dahlander & McFarland, 2013). Thus with the formation of a new dyad as part of a consortium, the social embeddedness of the dyads evolves, which on its turns leads to additional effects of embeddedness. From this premise, we challenge static perspectives on social embeddedness and argue that effects of past embeddedness are fundamentally dynamic.

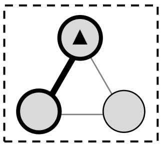
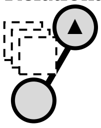
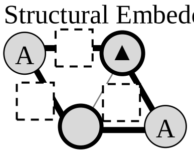
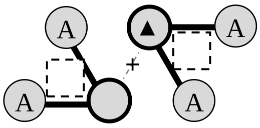
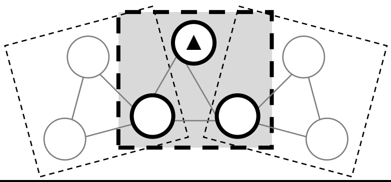
When a dyad is formed through a consortium the inter-organizational relation becomes embedded in the consortium, and the consortium, on its turn gets embedded in the wider inter-organizational network. In this way agents and their relations are exposed to different forces and co-evolve over time by the consortium embeddedness, e.g. when they accumulate joint knowledge and experience, opt for new research approaches because of having new consortium partners, develop shared or extended normative and evaluation frameworks, and when proximate frames of reference from past relationships get complemented by more distal frames of reference of the consortium and its surroundings. The consortium serves not only as social structure or context for the involved agents, but becomes a social entity with agentic properties itself. Therefore, the centrality of the consortium in the wider network has an influence on the likelihood that dyads within the consortium get repeated. This particular temporal dynamic of dyads embedded in a consortium, and a consortium that is embedded in an inter-organizational network is not captured in the typology of Gulati and Gargiulo (1999), and requires an extension of their original typology with consortium embeddedness (the centrality of the consortium in the network).

In order to develop a fine-grained understanding of the dynamics of all four types of embeddedness, we use a two-mode analysis (e.g. Breiger, 1974; Everett & Borgatti, 2013), and differentiate between two social entities – organizations and consortia – in the network. This allows us to examine the effect of consortium embeddedness, and to demonstrate whether consortia either serve as a random environment for the dyadic relation between a consortium leader and member, or over time as an alternative social entity besides the organization (e.g. Branstetter & Sakakibara, 2002; Das & Teng, 2002a; Doz, Olk, & Ring, 2000), that embeds the relationships between the leader and members.

The dynamics of our model are defined by using three different dependent variables for different time points in the life time of a dyad: when the tie is formed p(Formation), when the repeat of a tie occurs briefly after the tie formation $p(RC_{During})$, and when a tie is repeated after tie termination of the former tie $p(RC_{After})$. We consider an effect as temporal dynamic when size and or sign of any type of past embeddedness is different at two moments in time.

Comparing effects of past embeddedness on the likelihood of tie formation, repeated collaboration during the consortium, and after the consortium, provides insight in the temporal dynamic effects of past embeddedness. On the one hand, temporal dynamics caused by the consortium formation, become evident from differences in effects on p(Formation) versus p(RC_{During}). On the other hand, differences between p(RC_{During}) and p(RC_{After}) point towards temporal dynamics that occurred between the consortium formation and termination. Dynamics between the consortium formation and termination are associated with learning and evaluation over time (i.e. recency effect, that is fading out old experience relative to recent experience, and decay of value of information), while dynamics with the consortium formation can reflect sudden changes, e.g. due to conflicting agreements and obligations. Table 1 shows the possible effects of relational, structural, positional and consortium embeddedness on tie formation and repeated collaboration over time. E.g. for relational embeddedness, a difference between the

Table 1: Overview Temporal Dynamic Effects of Past Embeddedness

Past	**Present**	**Future**	
Outcome	**p(Formation)**	**p(RC_{During})**	**p(RC_{After})**
	Consortium start  Consortium end		
Antecedent			
Relational Embeddedness 	A	D	H
Structural Embeddedness 	B	E	I
Positional Embeddedness 	C	F	J
Consortium Embeddedness 		G	K

Consortium leader; Consortium member; Alter; Consortium effects observed in Cell A and Cell D point towards temporal dynamics that arose with the consortium formation, while differences between Cell D and Cell H must have descended between the consortium formation and termination.

3.3 TOWARD HYPOTHESES: LITERATURE REVIEW AND INTERVIEWS

In this part of the chapter, we follow an alternative approach for hypothesis development. For each aspect of our research model described in Table 1, we review the existing literature, and on top of that we use interview data to empirically substantiate our theoretical arguments. We chose this approach, because there is only a very limited amount of empirically validated dynamic models available that address the effect of past embeddedness on tie formation and repetition.

The formulation of hypotheses on the temporal dynamic effects of past embeddedness is based on a literature review. By means of Thomson ISI Web of Knowledge, we identified 39 papers that both build on the work of Gulati and Gargiulo (1999), and examine any temporal dynamic effect of past embeddedness.[14] Most studies explore effects of at least one of the four types of embeddedness (i.e. relational; structural; positional; consortium) on tie formation, repetition or dissolution. However, only 10 of the previous studies include more than one dependent variable – e.g. tie formation and tie dissolution – to compare embeddedness effects over time. For the 39 studies, we coded all discussed effects on the basis of the antecedent (relational; structural; positional; or consortium embeddedness), the type of effect (positive; negative; no effect), the mechanism, and the outcome (p(Formation); p(RC_{During}); p(RC_{After})). We identified six different mechanisms in the literature: Social integration (i.e. the development of shared norms, values and goals); trustworthiness (i.e. collective sanctioning and reputation effects); status and legitimacy (e.g. preferential attachment); access to information and resources; joint value creation and learning; and inertia (i.e. network opportunity and constraint). Table 2 shows the percentages of the aforementioned studies in which a given configuration of antecedent, effect, mechanism and outcome is observed. E.g. in 5% of the studies (Table 2 Cell A) it was argued that relational embeddedness (antecedent) has a positive effect (type) on tie formation (outcome), because of the resulting social integration (mechanism). Per study, we observed ca. 4 unique configurations of antecedents, effects, mechanisms and outcomes.

[14] In the first step, we searched for papers that cite Gulati and Gargiulo (1999). Second, we inserted a search string that included both 'embeddedness' and either 'time', or 'temporal' or 'dynamic*'. This step identified a pool of 61 papers. In the third step, we thoroughly evaluated every paper and selected 39 studies that discussed or examined any temporal dynamic effect of past embeddedness, i.e. any interaction between past embeddedness and time.

Table 2: Past Embeddedness Effects – Literature Review and Interview Results

	Outcome:	p(Formation)						$p(RC_{During})$						$p(RC_{After})$					
	Source:	**Literature**			**Interviews**			**Literature**			**Interviews**			**Literature**			**Interviews**		
Antecedent:	**Mechanism:** / **Effect:**	**+**	**0**	**–**	**+**	**0**	**–**	**+**	**0**	**–**	**+**	**0**	**–**	**+**	**0**	**–**	**+**	**0**	**–**
Relational Embeddedness	Social integration	5%	.	.	78%	12%	.	.	.	.	18%	4%	.	28%	3%	3%	65%	25%	.
	Trustworthiness	5%	.	.	16%	2%	2%	.	.	.	.	.	.	15%	3%	.	27%	.	6%
	Status and legitimacy	.	.	.	33%	.	.	.	.	.	.	.	.	.	.	.	14%	.	.
	Information access	8%	.	.	65%	2%	2%	3%	.	.	6%	.	2%	21%	.	15%	65%	2%	10%
	Value creation and learning	.	.	.	37%	6%	2%	.	.	.	8%	.	.	31%	.	.	82%	12%	6%
	Inertia	5%	.	.	31%	.	.	.	.	.	.	.	.	13%	.	10%	6%	.	.
	Any effect:	**18%**	**.**	**.**	**94%**	**16%**	**6%**	**3%**	**.**	**.**	**29%**	**4%**	**2%**	**54%**	**3%**	**26%**	**94%**	**31%**	**16%**
Structural Embeddedness	Social integration	3%	.	.	25%	.	.	.	.	.	.	.	.	26%	.	.	12%	6%	.
	Trustworthiness	8%	.	.	2%	.	2%	.	3%	.	.	.	.	26%	.	.	12%	2%	2%
	Status and legitimacy	.	.	.	10%	.	.	.	.	.	.	.	.	.	.	.	4%	.	.
	Information access	15%	.	.	37%	.	4%	.	.	3%	.	.	2%	15%	8%	3%	10%	6%	4%
	Value creation and learning	.	.	.	8%	2%	10%	.	.	3%	.	.	2%	13%	.	.	10%	2%	4%
	Inertia	3%	.	.	31%	.	.	.	.	.	.	.	.	21%	.	3%	4%	12%	.
	Any effect:	**15%**	**.**	**.**	**71%**	**2%**	**14%**	**.**	**3%**	**5%**	**.**	**.**	**2%**	**41%**	**8%**	**3%**	**39%**	**22%**	**8%**
Positional Embeddedness	Social integration	.	.	.	4%	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Trustworthiness	.	.	.	.	.	.	.	.	.	.	.	.	5%	.	.	.	.	.
	Status and legitimacy	15%	.	.	37%	.	.	3%	.	3%	.	.	.	8%	8%	3%	4%	.	.
	Information access	5%	.	3%	39%	.	2%	3%	.	.	.	.	.	8%	3%	10%	12%	4%	4%
	Value creation and learning	.	.	.	8%	.	.	.	.	.	.	.	.	3%	.	.	4%	.	2%
	Inertia	.	.	5%	4%	.	.	.	.	3%	.	.	.	3%	.	3%	.	.	.
	Any effect:	**15%**	**.**	**5%**	**57%**	**.**	**2%**	**3%**	**.**	**5%**	**.**	**.**	**.**	**15%**	**8%**	**10%**	**16%**	**4%**	**6%**
Consortium Embeddedness	Social integration	.	.	.	.	.	.	.	.	.	2%	.	4%	.	.	.	12%	.	.
	Trustworthiness	.	.	.	.	.	.	.	.	.	.	.	2%	.	.	.	.	.	.
	Status and legitimacy	.	.	.	.	.	.	.	.	.	4%	.	.	.	.	.	2%	.	.
	Information access	.	.	.	.	.	.	.	.	.	4%	.	.	3%	.	.	35%	10%	.
	Value creation and learning	.	.	.	.	.	.	.	.	.	.	.	.	3%	.	.	33%	6%	2%
	Inertia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Any effect:	**.**	**.**	**.**	**.**	**.**	**.**	**.**	**.**	**.**	**8%**	**.**	**4%**	**3%**	**.**	**.**	**51%**	**14%**	**2%**

Percentages of the 39 (literature) and the 51 (interview) observations in which a given effect is observed. E.g. 78% of the interviewees mentioned a positive effect of relational embeddedness on tie formation, because of social integration (Cell A). *Any effect* is the total percentage of observations, irrespective of the mechanism.

Besides the literature review, we conducted 51 interviews with consortium leaders and members, active in the Dutch water sector. The purpose of these interviews was to identify which theoretical mechanisms can be substantiated with these qualitative data. The sample of interviewees is stratified on the basis of the actor type (consortium leader / member), repeated collaboration experience, subfield, and consortium success. The semi-structured interview contained two open questions: “What were the most important reasons for you and your organization to join a consortium?” and “What are the most important reasons to continue this collaboration in a new consortium and/or to include a new consortium leader or members?” Interviews took approximately one hour. All interviews are recorded on tape and transcribed. Responses are coded on the basis of the configuration of antecedent, mechanism, effect and outcome. E.g. 78% of the interviewees mentioned that relational embeddedness enhances the social integration, which in turn fosters new tie formation (Table 2 Cell A). We observed ca. 10 unique configurations per interview, as displayed in Table 2. The results of the literature review and interviews are shown in Table 2. The hypotheses inferred from these results, are discussed below.

3.3.1 Hypotheses: Effects of Past Embeddedness on Tie Formation

With respect to the initial effects of past embeddedness on tie formation p(Formation), we investigated three types of embeddedness – relational, structural, and positional embeddedness – as the fourth, consortium embeddedness, can only occur once the consortium has been formed. Only a small percentage of the relevant literature examines the effects of past embeddedness on p(Formation), as shown in Cell A (18%), B (15%) and C (15%) of Table 2. However, it would be incorrect to conclude that this area is understudied. Conversely, Gulati and Gargiulo (1999) developed a solid baseline for the effects of past embeddedness on tie formation, which has since been extensively tested by numerous other scholars. The availability of this baseline allowed us to focus our literature review on papers that address temporal dynamic effects of past embeddedness, and to leave out papers that apply a static perspective on embeddedness. The results of the literature review do show, however, that only very few incorporate past embeddedness effects on *both* tie formation *and* repetition in a single study.

In the literature, the access to fine-grained information about a partner’s trustworthiness and competencies, is the most prevalent mechanism to explain how social embeddedness enhances the likelihood that two actors form a tie (Table 2 Cell A, B, C) (e.g. Dahlander & McFarland, 2013; Polidoro et al., 2011; Rivera, Soderstrom, & Uzzi, 2010; Shipilov, Rowley, & Aharonson, 2006). This information, either gained by direct experience, or via common partners, or through generalized information, is better than having no information at all, and therefore enhances the likelihood of tie formation p(Formation). In addition, past direct and indirect ties (Table 2 Cell A, B) increase the likelihood of tie formation by means of social integration (e.g. Rivera et al., 2010), trustworthiness safeguards (e.g. Polidoro et al., 2011; Shipilov et al., 2006) and inertia (e.g. Dahlander & McFarland, 2013; Kilduff, Tsai, & Hanke, 2006). Past positional embeddedness (Table 2 Cell C) mainly provides status benefits (e.g. Dahlander & McFarland, 2013; Kilduff et al., 2006; Polidoro et al., 2011). Only for positional embeddedness, a few studies mention a potential negative effect on p(Formation).

Table 2 shows in Cell A, B and C that the interview results indeed substantiate the aforementioned mechanisms explaining tie formation, with a few exceptions. It turns out that past direct and indirect ties enhance p(Formation) by means of information access, social integration and inertia. In addition to these mechanisms, interviewees report that actors also form new ties with past direct partners (Table 2 Cell A), because they anticipate status spillovers from these actors and opportunities for joint value creation. For indirect ties on the other hand (Table 2 Cell B), interview results show that trustworthiness safeguards are less prominent than suggested in the literature. Furthermore, indirect ties can be constraining in case of competition between both alters. One interview respondent stated for instance: “In this consortium [organization X] is involved and will not tolerate any of its direct competitors as consortium member”, which mitigates the potential for new partnerships. Although respondents do indicate some situations where past social embeddedness can have negative or no effect on tie formation, the positive effects are by far most prominent. However, not all embeddedness effects are equally prominent. A notable trend that is consistent with Granovetter’s (1985) initial notion of embeddedness, is that past direct ties – relational embeddedness (Cell A; 94%) – have a significantly stronger effect on p(Formation) compared to past indirect ties – structural embeddedness (Cell B; 71%) – which in turn have a stronger effect than generalized status and information effects from positional embeddedness (Cell C; 57%). Therefore we hypothesize:

Hypothesis 1: The effect of past relational embeddedness on p(Formation) is stronger compared to the effect of past structural embeddedness, which has a stronger effect compared to past positional embeddedness.

3.3.2 Temporal Dynamic Effects of Past Embeddedness

Neither the literature, nor the interviews, yielded much findings about past embeddedness effects on p(RC_{During}), i.e. the repetition of a tie briefly after the tie formation (Table 2 Cells D to G: 3%, 5%, 5%, 0% of the literature and 29%, 2%, 0%, 8% of the interviews). However those studies and respondents who do pay attention to this, indicate important developments, as discussed below. Conversely, embeddedness effects that affect repeated collaborations after the consortium p(RC_{After}), are widely debated (Cells H to K of Table 2). The existing literature suggests that the most prevalent predictor of p(RC_{After}), is relational embeddedness (Cell H; 54%), followed by structural embeddedness (Cell I; 41%), positional embeddedness (Cell J; 15%), whereas consortium embeddedness is seldomly mentioned (Cell K; 3%). Surprisingly, the interview results indicate otherwise (subsequently 94%, 39%, 16% and *51%* for Cells H to K). Particularly the effect of consortium embeddedness on $p(RC_{After})$ seems to be more prominent (51%) than mentioned in the literature (3%). To develop a fine-grained understanding of the observed temporal dynamics, we will successively discuss the effects for the four types of embeddedness.

Relational Embeddedness (RE). Relational embeddedness of the inter-organizational relation in the two-mode network is operationally defined as the number of prior consortia of which both ego (the focal unit) and alter (the partner) were a member. In that sense relational embeddedness describes the shared history of a dyad. Initially, direct experience that results from past collaborations provides fine-grained information about a partner's trustworthiness and competencies, as well as insights in new collaboration opportunities (Granovetter, 1985; Gulati, 1995a, 1995b; Gulati & Gargiulo, 1999) increasing the likelihood of tie formation (Table 2 Cell A).

According to past research, when ego and alter enter into a new consortium several mechanisms become active (Table 2 Cell D and H). On the one hand, their joint experience can further expand during the lifespan of the new consortium enhancing the likelihood of repeated collaboration. On the other hand, recent collaboration experience gained in the current consortium can outweigh and overshadow the experience gained from past consortia (Baum, Li, & Usher, 2000; Schwab & Miner, 2008), which on its turn mitigates the effect of past relational embeddedness over time. Our interview results substantiate both mechanisms. One consortium member argued: "You must maintain contact. It does not just happen, you have to work on it. This [consortium membership] is one way to do that". In line with this a consortium leader stated: "I have dedicated the last meeting to set up a new consortium, to present our plans and ask them for their input. I then received very positive feedback and everyone wanted to participate again." Both respondents indicate that the new consortium can serve to update past relational embeddedness, particularly in terms of social integration. On the other hand, one consortium member stated with respect to the relevance of past relational embeddedness: "The [consortium] start is easier perhaps. Because, if you know these people, you can position them in terms of their wants, stakes, and capabilities. But eventually, it will not have made much difference […]. After one or two meetings you know whom you are dealing with. Those meetings are long enough for that".

We infer from the literature review and interview results (Table 2 Cell D and H) that the effect of relational embeddedness is temporal dynamic. Partner-specific insights that results from past relational embeddedness provide ego and alter the opportunity for early repeats $p(RC_{During})$ briefly after the tie formation (Katila & Mang, 2003; Uzzi, 1997). But between the consortium formation and termination the emphasis shifts from social integration and information access to opportunities for joint value creation. The interview results substantiate this shift in emphasis and show that the prevalence of joint value creation increases from 37% for p(Formation) (Table 2 Cell A) to 82% for $p(RC_{After})$ (Cell H). With this shift in collaboration motives, the effect of past relational embeddedness gets somewhat obscured during the lifespan of the consortium. Due to information redundancy, unintended spillovers, and relationship exhaustion, interview respondents and the literature report increasing attention for absent or even negative effects of past social embeddedness on $p(RC_{After})$ (Table 2 Cell H). This pattern does not imply that the past embeddedness effect disappears completely between consortium formation and termination, but it does decline with the amount of time passing by. Given that the development of new insights and shared competences is a time consuming learning process, the decline of the initial relational embeddedness effect is most likely when the consortium comes to an end (Greve, Baum, Mitsuhashi, & Rowley, 2010). Therefore, we hypothesize:

Hypothesis 2a: The effect of past RE on p(Formation) is positive and equal to the effect of past RE on $p(RC_{During})$.

Hypothesis 2b: The effect of past RE on $p(RC_{During})$ *is positive and larger than the effect of past RE on* $p(RC_{After})$.

Structural Embeddedness (SE). Structural embeddedness of the inter-organizational relation in a two-mode network is operationally defined as the number of indirect ties, who have been common partners of ego and alter in prior consortia. The literature (Table 2 Cell B) has identified two mechanisms causing structural embeddedness to increase the likelihood of tie formation between ego and alter. First, common partners provide ego and alter with indirect channels for information, in the absence of a direct tie (Gulati & Gargiulo, 1999). Second, the third party can safeguard trustworthiness and norms of reciprocity (Obstfeld, 2005; Simmel, 1950), particularly when the indirect tie embeds a direct tie and provides network closure. As a consequence the formation of a new tie on the basis of an indirect tie is automatically an act of network closure.

Table 2 shows that only a small number of studies and interviewees discuss the effect of past structural embeddedness on $p(RC_{During})$ (Cell E). Those who do, however, consistently point toward absent or a negative effect of past structural embeddedness. Also for $p(RC_{After})$, the proportion of interview respondents that point towards an absent or negative effect of past structural embeddedness is relatively large in comparison to other embeddedness effects (Table 2 Cell I). To obtain a fine-grained understanding of the potential change in the embeddedness effect, we discuss some exemplary studies and interview responses in which the change over time is explicitly addressed. First, Shipilov, Rowley and Aharonson (2006) explain how indirect information channels loose most of their value with consortium formation:

> "The initial tie formation process – how organizations evaluate and choose new partners – focuses on mitigating partner uncertainty despite the lack of first-hand information. At this stage of a relationship, organizations rely on second-hand proxies such as firm attributes, third-party endorsements, clique membership and status positions. Once a tie has been formed, however, the evaluations are made on the basis of criteria specific to the partnership. Decision criteria move from external proxies (initial tie formation decisions) to factors internal to the partners (subsequent tie renewal/termination decisions)." (p. 490).

This reasoning finds support in our interview results, where several respondents alluded to the weakening of structural embeddedness effects during the lifespan of the consortium. Respondents argued that during the new consortium they found out that, for partnerships that arose from indirect ties, information flows and direct collaborations often times did not arise because these new partners where not always that reliable. Polidoro, Ahuja and Mitchell (2011) further extend this reasoning with the argument that indirect information channels and referrals indeed loose most of their value with consortium formation, but social restraint persists as a central mechanism:

> "[…] structural embeddedness provides two related but distinct types of benefits and that these benefits map differently onto the outcomes of tie formation and tie dissolution. The first benefit is that of referrals, whereby firms are knowledgeable about their partners and refer them to a focal firm (Burt, 1992; Gulati, 1995b). The second benefit is that of social restraint (Coleman, 1988; Dore, 1983). Alliance formation mainly reflects the referral benefits of having common partners, perhaps combined with some ex ante expectation of social restraint. Alliance dissolution, on the other hand, offers an opportunity for a closer test of the social restraint mechanism. At the time that firms consider the decision to terminate a relationship with a partner, the referral advantage is no longer relevant; the social restraint is, meanwhile, a valid consideration. […] systematically staying in a relationship longer, even in the face of competitive incentives to break the relationship, reflects the suppression of an atomistic, transactional calculus in favor of a longer-term, relational perspective." (p. 217).

This leaves open the question how past structural embeddedness, in the form of social restraint, affects the likelihood of repeated collaboration once the consortium is formed.

Dahlander and McFarland (2013) argue that the past structural embeddedness enhances both tie formation and persistence, because capacity for monitoring and sanctioning makes actors more likely "stick to those relationships" (p. 79) compared to a situation where such monitoring and evaluation is absent. In addition, Polidoro et al. (2011) state that "[...] as the number of common partners linking the two firms increases, the social monitoring effects become stronger" (p. 207). For multi-partner R&D consortia, we deviate from this reasoning and argue that the monitoring effects of different indirect ties do not add up that easily. After all, newly formed multi-partner consortia come also with new third parties that have their own expectations and demands. Therefore, obligations and agreements with the prior common partners (Coleman, 1988; Greve et al., 2010) might conflict with the expectations of the new common partners in the new consortium (Krackhardt, 1999). Particularly in case of multi-partner R&D consortia, conflicting expectations of old and new third parties might frustrate relationship persistence, due to secrecy and non-disclosure agreements made per consortium. One illustrative quote by a consortium member was:

> "Look, it might be that the consortium continues with the same partners, but it might also be that the first consortium aroused the interest of other partners that also join the new consortium. In the beginning of the new consortium that often times causes issues with respect to confidentiality and information sharing in the new consortium […] If you have already collaborated with two or three partners in a prior consortium, then you have already accumulated a certain amount of collective knowledge. Partially this will be published, partially not. When a third party comes in, then you should always ask yourself what to do with the knowledge [gained in the prior consortium] that the new partner does not possess. Do you share it [with the new partner], or not? And if you do, can the other party use it, or does it come with additional conditions with respect to publication and confidentiality. This often times causes quite some discussions with the legal departments."

Therefore, we argue that past structural embeddedness not only loses most of its information value once a new consortium is formed, but also turns into a liability due to conflicting obligations. We hypothesize:

Hypothesis 3a: The effect of past SE on p(Formation) is positive, while the effect of past SE on p(RC_{During}) is negative.

Hypothesis 3b: The effect of past SE on p(RC_{During}) is negative and equal to the effect of past SE on p(RC_{After}).

Positional Embeddedness (PE). Positional embeddedness of the inter-organizational relation in the two-mode network is operationally defined as the combined centrality of ego and alter that results from their prior individual consortium memberships. Accordingly, positional embeddedness results from the wider inter-organizational network beyond direct and indirect ties, and therefore is a source of generalized information. This generalized information about potential partners' abilities and trustworthiness is better than having no information at all and therefore enhances tie formation: "If two central firms choose each other as partners, they can ex ante expect to have made better partnering choices that will lead to a more stable alliance than partnering with noncentral firms" (Polidoro et al., 2011, p. 205).

However once a direct tie gets formed with a partner, generalized information about this specific partner might get enriched and partially overshadowed by firsthand experience gained from direct collaboration with this partner (Polidoro et al., 2011). What remains is generalized information about the developments and opportunities in the surroundings of the newly formed dyad. Once a dyad is formed, actors can apply two different strategies to make use of this information. They can use generalized information either to deepen the ongoing relation with new insights derived from the wider network or they can use the generalized information to broaden their partner portfolio replacing old ties for new ties. The literature review reveals strongly opposed views regarding the effect of past positional embeddedness on repeated collaboration during or after the consortium (Table 2 Cells F and J). On the one hand, positional embeddedness can enhance the likelihood of repeated collaboration, as continuing source of non-redundant information (Burt, 2005; Gilsing, Lemmens, & Duysters, 2007), that keeps the collaboration vital and allows for monitoring of trends and technological developments. In addition, a central network position may emit a continuous and self-reinforcing signal of trustworthiness (Provan, Huang, & Milward, 2009). On the other hand, possessing a central position in the network might turn into a liability, due to the finite number of ties that an actor can maintain (Dahlander & McFarland, 2013). Generalized information might be advantageous for the formation of new ties, but at the same time, the attention for new tie formation competes with the attention and resources that an organization can devote to the repetition of existing ties. In other words, actors that continuously form new ties with new partners and apply a strategy to broaden their partner portfolio, are less likely to repeat their existing relations, because they focus their attention on the formation of new ties at the expense of repeating existing ties. Thus, organizations with a central network position can apply two opposing strategies, they can either use generalized information to continuously renew their partner portfolio, or to keep existing relations vital.

Also the interview results point in opposing directions (Table 2 Cells F and J) which implies that even within one sector both strategies are used by different organizations. On the one hand, some respondents indicate that the knowledge and information held by central actors, do not become available during the consortium. Central actors are sometimes even perceived as a threat, because they are a source of potential knowledge spillovers to competitors. On the other hand, several respondents advocate the importance of central partners in the consortium. One interview respondent argued for instance: “[This research institute] is the party that ties it all together. This was and still is the central pivot in initiating cooperation with universities and [these consortia] on the one hand, and Joint Industry Projects on the other hand. [… They] really act as a hub for the entire knowledge platform in the Netherlands in this field. So you will have contact with them. [… They] really play a key role in this whole story, bridging between academia and business, so they should certainly be involved. They really are a driving force in this.”

For individual organizations, both the literature review and interviews yield inconclusive results regarding the effect of past positional embeddedness on the likelihood of repeated collaboration. Individual organizations that possess a central position can either use generalized information to continuously renew their partner portfolio or to keep existing relations vital and repeat them. However, we can infer from the interview results (Table 2 Cell J) that in our research setting, the number of organizations that use generalized information to repeat existing relations is seemingly larger than the number of organizations that use this information to replace existing relations with new relations (16% vs. 6%). Even though individual firms can choose between two competing strategies, at the population level central firms are more inclined to repeat their ties with central others than to replace them by new partners, in comparison to non-central organizations. Also in the literature (Table 2 Cell J) the repetition strategy is a more prevalent strategy for more central firms than the renewal strategy (15% vs. 10%). Therefore, we conjecture that the effect of past positional embeddedness on the likelihood of repeated collaboration (during or after the consortium) is positive, but to a considerably lesser extent than the effect of past embeddedness on the likelihood of tie formation.

Hypothesis 4a: The effect of past PE on p(Formation) is positive and larger than the effect of past PE on p(RC_{During}).
Hypothesis 4b: The effect of past PE on p(RC_{During}) is positive and equal to the effect of past PE on p(RC_{After}).

Consortium Embeddedness (CE). Consortium embeddedness (Table 2 Cells G and K) is defined as the network position of the consortium, in which the dyad between the consortium leader and member is nested. It is measured operationally as the centrality of the consortium in the two-mode network that results from overlapping members with other consortia. The notion of consortium embeddedness builds on Breiger's (1974) duality principle of two-mode networks. This duality refers to organizations deriving their frame of reference from the consortia they participate in, while these consortia derive their identity from the participating organizations, i.e. consortia and organizations serve for each other both as social structures and as social entities. Whereas relational, positional and structural embeddedness are attributes of the dyads, this is no longer the unit of analysis for consortium embeddedness. The unit of analysis shifts from the dyadic relation between the consortium leader and member to the consortium in which this dyad is nested. Obviously, consortium embeddedness cannot have an effect on the initial tie formation p(Formation) that shapes the consortium, but only on the likelihood of repeating those previously formed ties, during the consortium $p(RC_{During})$ or after the consortium $p(RC_{After})$.

There is a two-fold motivation for the inclusion of consortium embeddedness in our dynamic model. First, once two actors decide to form a tie through an R&D consortium, the consortium as social structure provides a new frame of reference in which the participants can exchange knowledge and information, develop shared routines, create joint value and give new meaning to old insights. I.e. when two actors form a new tie through an R&D consortium, their frames of reference from past collaborations are likely to modify and take on new meaning due to their embeddedness in the newly formed consortium. Simultaneously, the newly formed consortium as social entity becomes embedded in the wider inter-organizational network, which makes that the proximate frames of reference from past collaborations get complemented by more distal frames of reference of the consortium and its surroundings.

To clarify the meaning of consortium embeddedness, we identify three fundamental differences between networks in which consortia are the nodes connected through overlapping members versus networks in which consortia shape the relations between consortium leaders and members. First, the consortium is time bound by the lifespan of the underlying project, and therefore can only be embedded in the network for the duration of its existence. Second, the multi-partner consortium includes multiple relations between the consortium leader and participating members. For that reason, consortium embeddedness concerns a consortium level effect, assumed to be similar for all nested relations. Consortium embeddedness provides collective access to external resources and information which becomes accessible to all members. The information coming from such a social structure has more leverage, as it pertains to group culture, norms, and values, which define frames of reference for collaboration. Peer pressure might derive from such shared frames of reference. Third, consortia become embedded in the wider network by overlapping memberships with other consortia. Consortium embeddedness therefore is rooted in a substantively different network than the three previously discussed types of embeddedness.

Our literature review on temporal dynamic effects of past embeddedness showed only one study that examines effects that resembles consortium embeddedness (Table 2 Cell K). Rowley, Greve, Rao, Baum and Shipilov (2005) argued: “Whether a clique member stays or exits hinges on the creation of value within each clique and distribution of the created value among its members […]. The creation of rewards is a function of the network position of the group as a whole, while the distribution of rewards is a function of the network position of the individual member relative to other group members. In both cases, access to resources is the source of rewards […]” (p. 504). Besides this one study, our literature review provided little guidance for the development of hypotheses.

The interview results offer more guidance to develop hypotheses on consortium embeddedness (Table 2 Cell G and K). Consortium embeddedness turned out to be the second most prominent antecedent for repeated collaboration after the consortium $p(RC_{After})$ (Cell K: 51%). With the consortium formation, the effect of consortium embeddedness on $p(RC_{During})$ is still somewhat unclear (Cell G). On the one hand, respondents indicate that consortium embeddedness can provide status benefits and information access, while simultaneously a lack of social integration can hamper repeated collaboration. One consortium leader stated for instance: “You can start a parallel study, but then you have a little dilemma, because the research still is linked to [the consortium ...] and everything that happens within the consortium has a kind of confidential status.” A consortium member reasoned: “First, [the consortium] should become a whole group, and that always takes a while. At some point, you have to jointly agree which direction is followed there. That takes time.”

When consortium members have agreed on their goals, this will leverage the social integration, and will enhance the positive consortium embeddedness effect on repeating ties (Table 2 Cell K). Particularly information access and joint value creation between the consortium formation and termination enhance $p(RC_{After})$. One consortium leader commented: “If they [consortium members] are also involved in other consortia, there often is interaction [between the consortia], at least if the projects are similar, perhaps with a slightly different application. But if something comes out of [the other consortium] what is useful, then it will be communicated, yes.” And a consortium member added: “Representatives from the consortium were always put in those committees, the one who had the most expertise […] one time the one and other times the other, to spread the knowledge across the country and to keep the networks going.” The results show that the majority of the respondents are experiencing cross-consortium information sharing or joint value creation due to consortium embeddedness. This in turn enhances the likelihood of repeated collaboration between the consortium leader and members after the consortium end $p(RC_{After})$.

The interview results correspond to general observations in the literature on R&D consortia. This literature has demonstrated that organizations participate in R&D consortia to learn from others, get access to widely dispersed resources and skills, and for joint value creation (Doz & Hamel, 1998; W. W. Powell et al., 1996). However, the consortium members will not share their knowledge and resources unconditionally. Initially, member participation in other consortia comes with external obligations of these actors (Krackhardt, 1999), which can constrain opportunities for repeated collaboration. Over the lifespan of the consortium, the members first have to develop joint norms of reciprocity, after which they can enter into a time-consuming learning process of knowledge sharing and joint value creation, characterized by long time-horizons for returns (Das & Teng, 2002a; Doz et al., 2000). From the interview results and this literature we infer that initially consortium embeddedness is a liability, but between the consortium formation and termination, it can turn into fertile soils to repeat collaborations between the consortium leader and member organizations.

Hypothesis 5: The effect of CE on $p(RC_{During})$ is negative, while the effect of CE on $p(RC_{After})$ is positive.

Table 3 summarizes the hypothesized effects of the four types of social embeddedness on the likelihood of tie formation and repeated collaboration during and after the consortium. A formalized representation of our model is included in Appendix A

3.4 METHODS

3.4.1 Research Context

This study performs a longitudinal analysis of the formation and the repetition of 7346 ties between consortium leaders and consortium members in 1715 multi-partner R&D consortia, in an observation period of 22 years. All consortia are funded by one of the oldest Dutch governmental funding programs that foster R&D collaboration between universities and industry. Data was collected from annual evaluation reports of this program, including consortium membership lists, project descriptions and consortium outcome evaluations. All consortia consist of an academic consortium leader, affiliated to one of the Dutch Universities, and a user committee with an average of 4 to 5 representatives of industrial firms or service providers. The unit of analysis is the dyadic relation between the university representative (called: consortium leader) and the industry representative (called: consortium member), manifested in an R&D consortium. We focus on the dyad, because different dyadic relations within a single R&D consortium can result from many different antecedents and can be destined for different futures: one relationship might be repeated frequently, while another relationship might occur only once. We consider the network resulting from these consortium memberships

Table 3: Hypothesized Effects of Past Embeddedness

Antecedent	p(Formation)	p(RC_{During})	p(RC_{After})
H1:	**RE > SE > PE**		
Relational Embeddedness: Number of prior consortia of which ego and alter were both a member.	A Positive effect: Prior direct experience encourages new tie formation by means of social integration, access to fine-grained information, and joint value creation opportunities.	D Positive effect: Prior direct experience facilitates early repeats during the consortium, because both parties already possess partner-specific insights, and are social integrated.	H No or small effect: Between the consortium formation and termination, the added value of prior direct experiences is canceled out by newly gained experiences from the current consortium.
H2ab:	**RE on p(Formation) =**	**RE on p(RC_{During}) >**	**RE on p(RC_{After}).**
Structural Embeddedness: Number of prior common partners of ego and alter (indirect ties).	B Positive effect: Prior common partners stimulate new collaborations, both as indirect channels for information about the others, and as mediator to reduce potential conflict, and due to inertia.	E Negative effect: Social monitoring by prior common partners becomes a liability in meeting obligations of the new consortium. Prior indirect information channels lose their value with the formation of a direct tie.	I Negative effect: Conflicting norms and obligations to prior partners and current consortium members are a prolonged inhibition of the continuation of the relation.
H3ab:	**SE on p(Formation) <>**	**SE on p(RC_{During}) =**	**SE on p(RC_{After}).**
Positional Embeddedness: Prior combined centrality of ego and alter in the two-mode network.	C Positive effect: Centrality fosters new collaborations, as source of generalized information about potential partners, visibility and status (social capital).	F Positive effect: Although maintaining many ties is time consuming, positional embeddedness remains a source of non-redundant information that can keep the collaboration vital.	J Positive effect: Although maintaining many ties is time consuming, positional embeddedness remains a source of non-redundant information that can keep the collaboration vital.
H4ab:	**PE on p(Formation) >**	**PE on p(RC_{During}) =**	**PE on p(RC_{After}).**
Consortium Embeddedness: Centrality of the consortium in the two-mode network.	Not applicable: The consortium must first be formed.	G Negative effect: Consortium centrality based on member overlap with other consortia initially comes with many external obligations of these members.	K Positive effect: Once norms of reciprocity are in place in the consortium, knowledge spillovers from external consortia provides long-term opportunities for learning and joint value creation.
H5:		**CE on p(RC_{During}) <>**	**CE on p(RC_{After}).**

= The effect of past embeddedness on T_0 is equal to the effect of past embeddedness on T_1;
> The effect of past embeddedness on T_0 is larger than the effect of past embeddedness on T_1;
< The effect of past embeddedness on T_0 is smaller than the effect of past embeddedness on T_1;
<> The effect of past embeddedness on T_0 is reverse to the effect of past embeddedness on T_1.

as a two-mode network (e.g. Breiger, 1974; Everett & Borgatti, 2013), because relations between the consortium leader and industrial firms is constituted by the consortia. The university and industry representatives are one type of social unit (or node), and the consortium is a second type of social unit (node). Examining two-mode embeddedness comes with two assumptions regarding the functioning of the network, that is: a) the consortium leader and members actually interact in the R&D consortium, which is a precondition for the funding of the consortia in our research context; b) consortia that have partially overlapping members are exposed to the mutual resource spillovers and constraints of other consortia, and increasingly so for more embedded consortia. This assumption is tested by the consortium embeddedness condition in our dynamic model.

3.4.2 Measures

Tie Formation. The choice set for tie formation includes all possible dyads between currently active consortium leaders and members, per year and application area. Accordingly, tie formation p(Formation) is observed (1) if a consortium leader and a member jointly participate in the same consortium and thus form a dyad, and tie formation is not observed (0) if a consortium leader and member both do participate in different consortia in a given application area and year, but *not* jointly in the same consortium. We defined a relatively restrictive choice set for p(Formation) to reduce the number of ties that are theoretically possible but empirically unlikely – e.g. because in a given year an organization was not active anymore or not yet established – and to exclude all kinds of exogenous explanations for non-formation of ties. Gulati and Gargiulo (1999) already demonstrated that, for tie formation, broader and more restrictive choice sets resulted in comparable outcomes.

Repeated Collaboration. Repeated collaboration concerns the repeated participation of a consortium leader and a member in two or more R&D consortia over time. We distinguish *repeated collaboration during the consortium* p(RC_{During}) from *repeated collaboration after the consortium* p(RC_{After}), because both types of repeated collaboration can result from substantially different types of embeddedness and can point towards different temporal dynamic effects of embeddedness. It is important to note that repeated collaboration during the consortium concentrates shortly after the consortium start (on average ca. 1.6 years), while repeated collaboration after the consortium concentrates shortly after the consortium end (on average ca. 1.7 years after the end). Collaborations that are not repeated within the observation period are considered right-censored.

Relational Embeddedness. It is typical for two-mode networks that relational embeddedness, the history of a 'direct relations' between the consortium leader and member (one mode), is operationally defined as the number of prior consortia of which both were a member (the other mode). Every time a consortium member and leader jointly participate in a consortium, a direct tie is formed between the two. Relational embeddedness is measured by means of a five year moving window preceding a given observation year. Alternative moving windows (one year; ten years) are examined, and discussed in the robustness test section.

Structural Embeddedness. Structural embeddedness – the number of past indirect ties (common partners) between the consortium leader and member – can occur in two forms:

firstly, in presence of a direct tie between the consortium leader and member (closure in a prior consortium including the focal consortium leader, member and a third party), and secondly, in absence of a direct tie (the focal consortium leader and member participate in two distinct prior consortia with a common third party). Both forms are included in this study. Also for structural embeddedness we used a five year moving window.

Positional Embeddedness. In line with previous research (e.g. Gulati & Gargiulo, 1999; Mizruchi, 1993; Podolny, 1994; Polidoro et al., 2011), we used Bonacich's (1987) eigenvector centrality to compute the relative network centrality scores of the consortium leader and the consortium member. We expressed the scores relative to the most central consortium leader respectively consortium member in the given year and application area. Next, to compute the combined centrality, we used the geodesic mean (Mizruchi, 1993) of the consortium leader's and consortium member's average centrality scores over the five year observation period.

Consortium Embeddedness. We introduce consortium embeddedness as a new dimension of embeddedness in two-mode networks. Consortium embeddedness is operationally defined as the centrality of the consortium in the two-mode network that results from overlapping members with other consortia. It is only recently that measurement models have been developed for two-mode networks (e.g. Borgatti & Everett, 1997; Everett & Borgatti, 2013) and integrated in UCINET (Borgatti, Everett, & Freeman, 2002). We used the UCINET two-mode eigenvector centrality to compute the relative network centrality score of the consortium in a particular year and application area. Eigenvector centrality scores based on the two-mode network or a one-mode representation of the two-mode network are equivalent (Bonacich, 1987; Borgatti & Everett, 1997; Everett & Borgatti, 2013). We expressed the scores relative to the most central consortium in that year and application area. Next, we computed the observation period average score. Contrary to the previous three types of embeddedness, consortium embeddedness is not measured over the five year time period preceding the formation of the initial collaboration, but over the period from the year of consortium formation to either the year preceding the consortium end or the year prior to the repeated collaboration. Consortium embeddedness is a consortium level effect, because the consortium centrality score in a given year is the same for all of its members.

Control Variables. To control for variance that results from unobserved temporal factors and for the network-level effects examined in previous research (e.g. Gulati & Gargiulo, 1999; Schilling & Phelps, 2007), we included application area dummies (ref. 'Instruments') and observation year dummies (ref. '2004'). The reference category has no implications for our findings, because we estimated the marginal effects based on all observations in the data. To control for organization-level unobserved effects, we included the past experience and the current activity of the consortium leader and of the consortium member. Past experience is operationally defined as the number of past consortia in which the consortium leader or member has participated in the five year period preceding the observation year. Current activity is operationally defined as the number of current consortia in which the consortium leader or member participates in the observation year. Positional similarity (e.g. Gulati & Gargiulo, 1999; Polidoro et al., 2011) is included as relation-level control variable, concerning absolute difference in eigenvector centrality of the consortium leader and member. In addition, we included consortium size and consortium duration as consortium-level control variables. Finally, non-independence of observations was corrected by means of network autocorrelation terms (Leenders, 2002). We used two-mode network autocorrelation terms (Fujimoto, Chou, & Valente, 2011), with separate 'exposure terms' for p(Formation), p(RC_{During}), and p(RC_{After}). The network exposure term measures the extent to which the consortium member is exposed to tie formation or repetition by other consortium members in the five year period preceding the observation year.

3.4.3 Modeling

To research the effect of past embeddedness on current tie formation (Equation I) and future repeated collaboration (Equation II), we used Van de Ven and Van Pragg's (1981) probit model with sample selection correction, which is a special type of a two-stage Heckman (1979) selection model. The Heckman selection models (e.g. Fleming, Mingo, & Chen, 2007; Katila & Mang, 2003; Polidoro et al., 2011; Uzzi, 1999), and their probit based counterparts (e.g. Gulati & Westphal, 1999; Reuer & Ragozzino, 2012; Westphal, Gulati, & Shortell, 1997) are frequently used when one dependent variable (repeated collaboration) is conditional upon another dependent variable (tie formation). In our study, the selection equation (I) models the likelihood of tie formation p(Formation), and the conditional equation (II) models the likelihood of future repeated collaboration p(RC). To examine the timing of repeated collaboration, we used two alternative conditional equations for p(RC_{During}) and p(RC_{After}), besides the equation for 'general' repeated collaboration. The correlation between the error terms of both the selection equation (I) and the conditional equation (II) is expressed in the term rho (ρ). If $\rho = 0$, the log likelihood of the Heckman model equals the joint likelihood of both independent equations, i.e. the sample selection effect is not significant and a regular probit regression model without sample selectivity correction is adequate. If $\rho \neq 0$, a regular probit regression model would produce biased estimates and the Heckman model is required.

In both equations, we controlled for the experience and activity of the consortium leader and member, positional similarity and network autocorrelation. In equation (II), we additionally controlled for consortium size and duration, because these effects can only occur once the consortium is formed. The year dummies and application area dummies – i.e. exogenous temporal and network-level effects at the time of consortium formation – are only included in equation (I) and serve as an instrument for the sample selection term in equation (II). Both equations include the independent variables relational, structural and positional embeddedness, and in equation (II) consortium embeddedness is added.

We used heteroscedasticity-robust standard errors (Bascle, 2008) adjusted for dyad-level clustering to allow for non-independence of observations pertaining to the same dyadic relation between a consortium leader and a member. Standard error adjustment at the dyad-level is preferred in this study, because: a) particularly dyad-level unobserved heterogeneity might be problematic in our dynamic model; b) adjustment for consortium-level clustering is not possible for the majority of the observations in equation (I); and c) adjustment for two-way clustering (Kleinbaum, Stuart, & Tushman, 2013) does not allow for the estimation of marginal effects. We consider the computation of average marginal effects to be of central importance for our study, because in logit and probit models "a change in a variable changes the probability of the focal outcome. However, […] the effect of a change in one variable depends on the initial probability of the event occurring (equivalently, on the values of the other variables)" (Hoetker, 2007, p. 334). Therefore, we computed the average marginal effects of past embeddedness on the basis of the observed scores for all other variables in the model, to deal with the interdependence of effects in the model.

3.5 Results

Table 4 and 5 show the descriptive statistics and correlations respectively for the selection equation p(Formation) and the conditional equations p(RC); p(RC_{During}) and p(RC_{After}). The likelihood that a consortium leader and member form a tie is 8.6% (of 85552 observations), which shows that consortium leaders do not just work with any organization in a field, and vice versa, but are selective in their partner choice. For more than 98% of the possible dyads p(Formation) is really the formation of a new tie with a 'stranger' (as in D. Li, Eden, Hitt, & Ireland, 2008) – i.e. the relational embeddedness is zero – and only a small part of the possible dyads has a shared history. Once formed, the likelihood that a consortium leader and member repeat their collaboration is 11.1% (out of 7346 observations) of which 6.9% during the consortium p(RC_{During}) and 4.1% after the consortium p(RC_{After}). These figures show that past embeddedness is not unconditionally replicated into current social structures. On the contrary, the vast majority of relationships within the funding scheme gets dissolved when the consortium ends. Table 4 and 5 show relatively strong correlations between relational and structural embeddedness (0.697 and 0.714), but the low Variance Inflation Factors (observed maximum: 2.541) show that there is no problem of multicollinearity.

Table 4: Descriptive Statistics and Correlations – Selection Equation

	Variables	Mean	S.D.	1	2	3	4	5
1	Tie formation	0.086	0.280	1.000				
2	Consortium Leader Experience	0.543	1.090	0.016***	1.000			
3	Consortium Member Experience	2.303	4.939	0.086***	0.017***	1.000		
4	Consortium Leader Activity	1.056	0.307	0.031***	0.175***	-0.012***	1.000	
5	Consortium Member Activity	1.314	0.861	0.145***	-0.009*	0.542***	0.006†	1.000
6	Positional Similarity	0.471	0.482	-0.001	-0.279***	-0.343***	-0.048***	-0.195***
7	Network Autocorrelation	0.503	0.694	0.020***	0.011**	0.348***	-0.002	0.211***
8	Relational Embeddedness	0.017	0.158	0.202***	0.195***	0.161***	0.043***	0.099***
9	Structural Embeddedness	0.064	0.446	0.159***	0.246***	0.188***	0.038***	0.093***
10	Positional Embeddedness	0.015	0.060	0.089***	0.357***	0.318***	0.065***	0.163***

85552 observations; † p < 0.100; * p < 0.050; ** p < 0.010; *** p < 0.001.

Table 4: Descriptive Statistics and Correlations – Selection Equation [Continued]

	6	7	8	9
6	1.000			
7	-0.512***	1.000		
8	-0.002	0.071***	1.000	
9	-0.013***	0.095***	0.697***	1.000
10	-0.040***	0.190***	0.413***	0.602***

Table 5: Descriptive Statistics and Correlations – Conditional Equation

	Variables	Mean	S.D.	1	2	3	4	5
1	Repeated Collaboration	0.111	0.314	1.000				
2	RC During Consortium	0.069	0.254	0.774***	1.000			
3	RC After Consortium	0.041	0.199	0.589***	-0.057***	1.000		
4	Consortium Leader Experience	0.600	1.202	0.143***	0.188***	-0.014	1.000	
5	Consortium Member Experience	3.692	7.741	0.073***	0.079***	0.014	0.036**	1.000
6	Consortium Leader Activity	1.087	0.374	0.175***	0.214***	0.003	0.210***	-0.012
7	Consortium Member Activity	1.721	1.474	0.101***	0.110***	0.020†	-0.013	0.657***
8	Positional Similarity	0.469	0.472	-0.055***	-0.060***	-0.011	-0.195***	-0.323***
9	Consortium Size	5.828	3.297	-0.060***	-0.035**	-0.050***	0.047***	-0.113***
10	Consortium Duration	4.666	1.410	-0.033**	0.029*	-0.088***	0.044***	0.010
11	Network Autocorrelation	0.127	0.284	0.021†	0.026*	0.000	0.136***	0.181***
12	Relational Embeddedness	0.121	0.424	0.143***	0.172***	0.005	0.479***	0.182***
13	Structural Embeddedness	0.296	1.086	0.068***	0.091***	-0.009	0.407***	0.162***
14	Positional Embeddedness	0.032	0.106	0.090***	0.107***	0.006	0.411***	0.346***
15	Consortium Embeddedness	0.280	0.290	-0.010	-0.018	0.007	0.138***	0.227***

7346 observations; † p < 0.100; * p < 0.050; ** p < 0.010; *** p < 0.001.

Table 5: Descriptive Statistics and Correlations – Conditional Equation [Continued]

	6	7	8	9	10	11	12	13	14
6	1.000								
7	0.041***	1.000							
8	-0.050***	-0.263***	1.000						
9	-0.040***	-0.106***	0.081***	1.000					
10	0.005	0.033**	-0.022†	0.141***	1.000				
11	0.029*	0.136***	-0.307***	-0.016	0.031**	1.000			
12	0.078***	0.069***	-0.007	-0.024*	0.003	0.146***	1.000		
13	0.051***	0.053***	0.003	0.050***	0.016	0.124***	0.714***	1.000	
14	0.077***	0.188***	-0.005	-0.004	0.015	0.156***	0.524***	0.625***	1.000
15	-0.011	0.208***	-0.155***	0.475***	0.082***	0.132***	0.059***	0.117***	0.204***

Table 6 displays the results of the sample selection probit regression on the likelihood of tie formation (first stage) and repeated collaboration (second stage) between a consortium leader and a member, corrected for the potential sample selection bias. The selection equation for p(Formation) is identical for all represented models, while the conditional equation is specified for model 1 ‘general’ p(RC), model 2 p(RC_{During}), and model 3 p(RC_{After}). The model fit to the data is examined by means of log-likelihood ratio tests (Long & Freese, 2006). The model fit and improvement of fit in Table 6 are statistically significant for all models. The statistical significance of the selection equation indicates that the selection term is well instrumented. For model 2 p(RC_{During}), the sample selection effect is not significant, which means that the sample used to estimate p(RC_{During}) is equivalent to any random sample of all possible dyads in the research setting, i.e. the sample of formed ties used to predict p(RC_{During}) is similar to any sample of possible ties. For model 1 p(RC) and 3 p(RC_{After}), the sample selection effects are statistically significant, indicating that selection of the sample in the second stage is not a random process, which justifies the use of a Heckman selection model. The improvement of fit in Table 6 shows for all two-stage models that the inclusion of the independent variables – relational, structural, positional and consortium embeddedness – gives a statistically significant improvement of fit to the data, compared to the models with only the control variables.

With respect to the control variables, Table 6 shows that more experienced consortium leaders are less likely to form ties p(Formation), but once formed, more likely to repeat these collaborations, particularly during the consortium p(RC_{During}). Consortium leaders and members that are very active, i.e. that participate in many consortia in the observation year, are more likely to form ties p(Formation) and repeat these collaborations briefly after the tie formation p(RC_{During}). These results show that not only relationship characteristics, but also consortium leader and member characteristics play an important role in the formation and persistence of ties. Particularly consortium leader activity is a strong predictor, demonstrating that agency does matter. The results for positional similarity show a positive effect on p(Formation), but a negative effect on p(RC_{During}), supporting Dahlander and McFarland’s (2013) initial conclusion that similarity effects on tie formation do not translate one on one to relationship continuation. Finally, the consortium size and duration mainly reduce p(RC_{After}). The strong shift over time, from organization characteristics as predictors for repeated collaboration during the consortium to consortium characteristics as predictors for repeated collaboration after the consortium, provides a first indication of the assimilation process that occurs within these consortia.

Relational embeddedness has a statistically significant positive effect on p(Formation) (Table 6 Cell A) and on p(RC_{During}) (Cell D), while the effect on p(RC_{After}) is not significant

Table 6: Sample Selection Probit Regression of Likelihood Tie Formation and Repeated Collaboration

	Selection Equation (1,2,3) Tie formation			Conditional Equation 1 Repeated Collaboration		Conditional Equation 2 Repeated Collaboration During Consortium			Conditional Equation 3 Repeated Collaboration After Consortium		
Intercept	-1.940***		(0.038)	-0.879***	(0.249)	-2.259***		(0.284)	0.181		(0.241)
Consortium Leader Experience	-0.042***		(0.008)	0.097***	(0.017)	0.134***		(0.020)	-0.027		(0.026)
Consortium Member Experience	-0.002		(0.002)	-0.001	(0.003)	0.001		(0.004)	-0.003		(0.004)
Consortium Leader Activity	0.146***		(0.017)	0.429***	(0.078)	0.554***		(0.092)	-0.032		(0.053)
Consortium Member Activity	0.219***		(0.008)	0.038†	(0.022)	0.091***		(0.023)	-0.057*		(0.027)
Positional Similarity	0.047**		(0.018)	-0.107*	(0.049)	-0.121†		(0.062)	-0.068		(0.059)
Consortium Size				-0.019*	(0.007)	0.002		(0.009)	-0.044***		(0.010)
Consortium Duration				-0.035*	(0.015)	0.036*		(0.017)	-0.129***		(0.021)
Network Autocorrelation	0.017		(0.012)	-0.127	(0.078)	-0.232		(0.188)	-0.290		(0.401)
Relational Embeddedness	1.046***	A	(0.106)	0.166†	(0.092)	0.324**	D	(0.097)	-0.194	H	(0.124)
Structural Embeddedness	0.104***	B	(0.025)	-0.118***	(0.029)	-0.092**	E	(0.033)	-0.107**	I	(0.040)
Positional Embeddedness	-0.657***	C	(0.158)	0.318	(0.251)	0.195	F	(0.275)	0.511	J	(0.352)
Consortium Embeddedness				-0.137	(0.085)	-0.386**	G	(0.118)	0.248*	K	(0.104)
Rho				-0.334	(0.089)	-0.116		(0.109)	-0.475		(0.090)
Sample selection effect				11.930***		1.120			19.820***		
Stage	First			Second		Second			Second		
Year dummies	Yes			No		No			No		
Application area dummies	Yes			No		No			No		
Log Likelihood	-22874.700			-25239.000		-24500.120			-24083.580		
df	36			12		12		12	12		
Model fit (Chi^2)	4361.350***			164.110***		203.720***			120.290***		
Overall Improvement				1458.480***		1479.050***			1430.500***		
N	85552			7346		7346			7346		

Standard errors in parenthesis; † $p < 0.100$; * $p < 0.050$; ** $p < 0.010$; *** $p < 0.001$.

(Cell H). Structural embeddedness has a statistically significant positive effect on p(Formation) (Cell B) and a negative effect on p(RC_{During}) and p(RC_{After}) (Cell E and I). Contrary to our expectations, positional embeddedness has a statistically significant negative effect on p(Formation) (Cell C) and no significant effect on p(RC_{During}) and p(RC_{After}) (Cell F and J). Finally, consortium embeddedness has a statistically significant negative effect on p(RC_{During}) (Cell G) and positive effect on p(RC_{After}) (Cell K).

Table 7 shows the average marginal effects of past embeddedness on the likelihood of tie formation and repeated collaboration (Top half of Table 7). In general, both the directions of effects and significance levels are consistent with the results in Table 6. Two deviations should be noted: First, relational embeddedness has a positive, though relatively small, statistically significant effect on p(RC_{After}) (Top half of Table 7 Cell H). So even after the consortium ends, the history of prior collaborations has some positive effect on the likelihood of repeated collaboration, but this effect is significantly mitigated by the newly gained experience in the consortium. Second, the effect of structural embeddedness on p(RC_{After}) is only marginally significant (Top half of Table 7 Cell I).

Table 7: Marginal Effects of Past Embeddedness

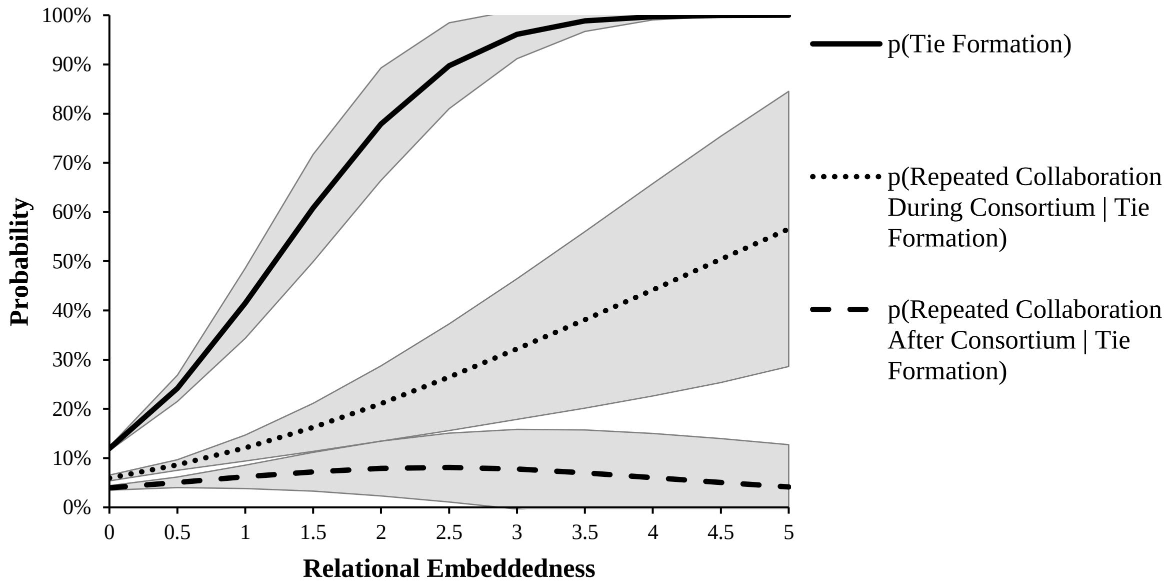
	p(Tie formation)		p(Repeated Collaboration | Tie formation)	p(Repeated Collaboration During Consortium | Tie formation)		p(Repeated Collaboration After Consortium | Tie formation)	
Relational Embeddedness	0.201***	A	0.082***	0.049***	D	0.021*	H
Structural Embeddedness	0.020***	B	-0.016**	-0.010**	E	-0.006†	I
Positional Embeddedness	-0.127***	C	0.026	0.016	F	0.024	J
Consortium Embeddedness			-0.025	-0.045**	G	0.023*	K
Predicted probability	15.8%		11.0%	6.9%		4.1%	
Relational Embeddedness	Δ 3.3%	A	Δ 3.9%	Δ 2.4%	D	Δ 1.0%	H
Structural Embeddedness	Δ 0.9%	B	Δ -1.7%	Δ -1.0%	E	Δ -0.6%	I
Positional Embeddedness	Δ -0.7%	C	Δ 0.3%	Δ 0.2%	F	Δ 0.3%	J
Consortium Embeddedness			Δ -0.7%	Δ -1.2%	G	Δ 0.7%	K

7346 observations; † $p < 0.100$; * $p < 0.050$; ** $p < 0.010$; *** $p < 0.001$; Δ difference in the probability of outcome = 1, related to an increase in past embeddedness of 1 standard deviation from the mean.

The bottom half of Table 7 shows the differences in the predicted probability of tie formation (15.8%) and repeated collaboration (11.0%; during 6.9%; after 4.1%) as a function of an increase in past embeddedness with one standard deviation (SD) from the mean. This allows to compare the strengths of the different effects and to relate the effects to the average predicted probability of an outcome to be 1. The marginal effects are computed over the 7346 cases that meet the selection criterion. Results show that the effect of relational embeddedness on p(Formation) (Bottom half of Table 7 Cell A: +3.3%) is stronger compared to the effect of structural embeddedness (Cell B: +0.9%), which has a stronger effect compared to positional embeddedness (Cell C: -0.7%), confirming hypothesis 1. To test the statistical significance of these differences, we applied Bonferroni adjusted post hoc tests on the marginal effects. These tests confirm hypothesis 1 that the effect of relational embeddedness on p(Formation) is statistically significant stronger ($p < 0.050$) than the effect of structural embeddedness on p(Formation), which in turn is stronger than the effect of positional embeddedness on p(Formation).

Second, the bottom half of Table 7 shows that the effect of relational embeddedness decreases between the consortium formation and termination. The effect of relational embeddedness on the p(Formation) (Cell A: +3.3%) is positive and somewhat stronger than the effect of $p(RC_{During})$ (Cell D: +2.4%), which is positive and notably stronger than the effect on $p(RC_{After})$ (Cell H: +1.0%). We examine our findings by means of an additional analysis based on Cumming's (2009) inference rule "that an overlap of half the length of one arm [of a confidence interval] corresponds approximately to statistical significance at p=0.05" (p. 205). Bonferroni adjusted post hoc tests cannot be applied across different models. Figure 1 shows the marginal effect of relational embeddedness on p(Formation), $p(RC_{During})$, and $p(RC_{After})$ over approximately the full range of the observed variable. The confidence intervals for p(Formation) and $p(RC_{During})$ do not overlap and provide only partial confirmation of hypothesis 2a: Despite the fact that the direction and significance of the two past embeddedness effects correspond, the strength of the effect differs significantly. The confidence intervals for

Figure 1: Marginal Effects *Relational* Embeddedness

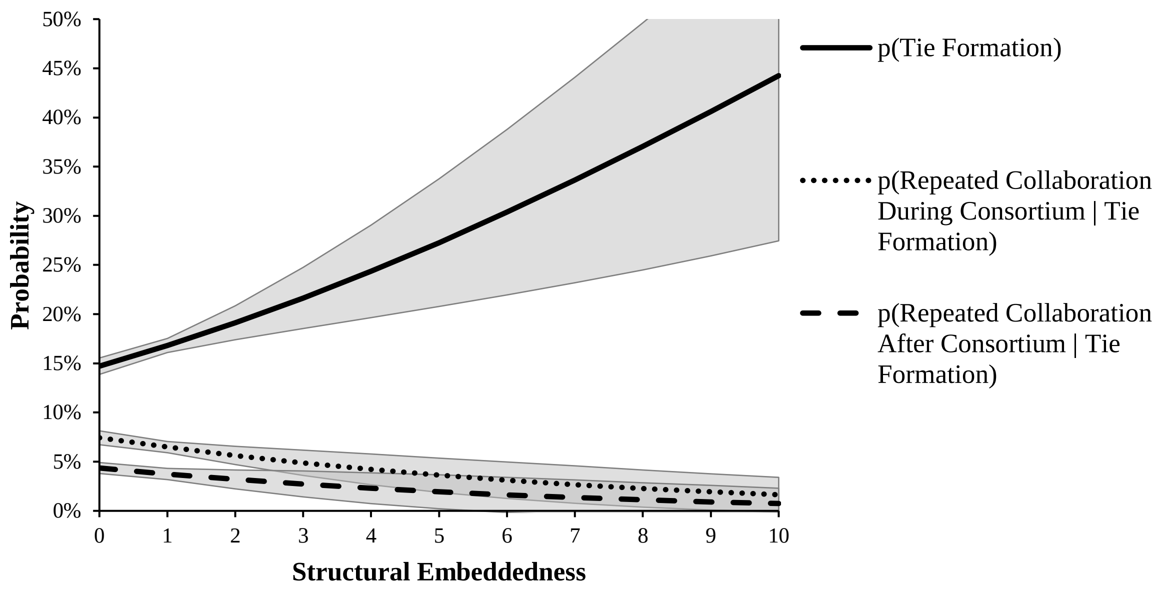


7346 observations; † p < 0.100; * p < 0.050; ** p < 0.010; *** p < 0.001.

p(RC_{During}) and p(RC_{After}) differ also significantly, confirming hypothesis 2b that the effect of relational embeddedness on p(RC_{During}) is stronger than the effect on p(RC_{After}).

Third, the bottom half of Table 7 displays that structural embeddedness has a positive effect on p(Formation) (Cell B: +0.9%), and a negative effect on subsequently p(RC_{During}) (Cell E: -1.0%), and on p(RC_{After}) (Cell I: -0.6%). This implies that the effect of structural embeddedness switches from positive before the consortium formation to negative after the consortium formation. This observation becomes even more apparent from Figure 2 that shows the marginal effect of structural embeddedness on p(Formation), p(RC_{During}), and p(RC_{After}). The effect of structural embeddedness on p(Formation) is positive and relatively strong, confirming hypothesis 3a, while the effects on p(RC_{During}) and p(RC_{After}) are equally negative, confirming hypothesis 3b. We have conducted an additional analysis in order to differentiate between the effect of past structural embeddedness in the *absence* and in the *presence* of a past direct tie between the consortium leader and member – i.e. structural embeddedness as indirect channels for information versus past network closure. It turns out that the positive effect of structural embeddedness on p(Formation) results from indirect ties in the absence of a direct tie, while the negative effect of structural embeddedness on p(RC_{During}) and p(RC_{After}) is caused by past network closure due to the conjunction of indirect and direct ties.

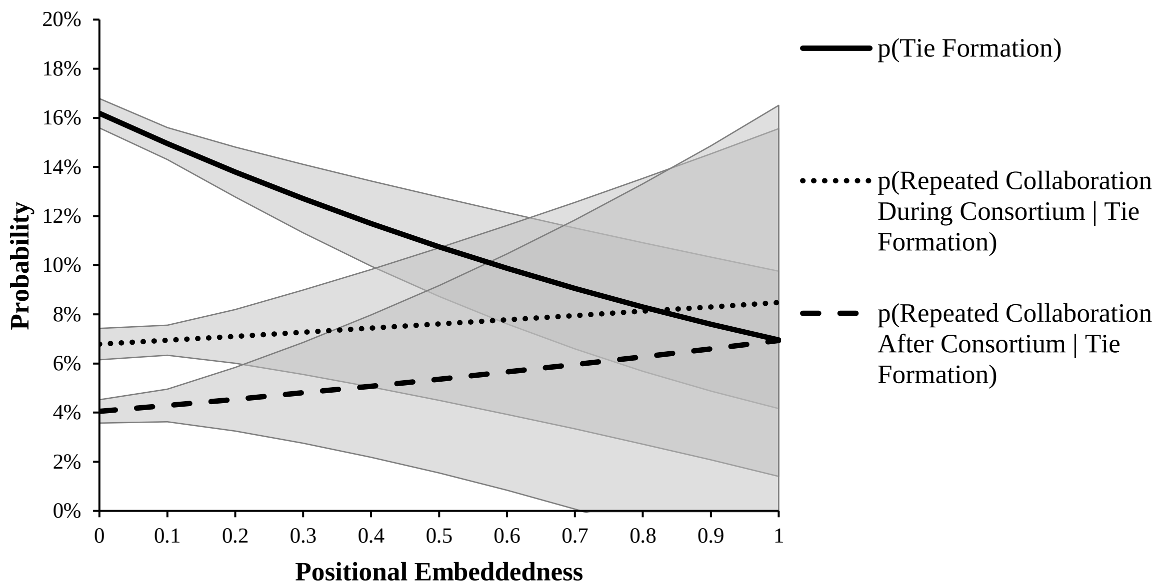
Figure 2: Marginal Effects *Structural* Embeddedness



7346 observations; † $p < 0.100$; * $p < 0.050$; ** $p < 0.010$; *** $p < 0.001$.

Fourth, the effect of positional embeddedness on p(Formation) is negative (Bottom half of Table 7 Cell C: -0.7%), while the effects on subsequently the p(RC_{During}) and p(RC_{After}) are positive but not significant (Cell F and J: +0.2% and +0.3%). I.e. the effect of positional embeddedness switches from negative before the consortium formation to positive after the consortium formation. The findings make us *reject* hypothesis 4a, that the effect of positional embeddedness on p(Formation) is positive and larger than the effect of positional embeddedness on p(RC_{During}). The findings confirm hypothesis 4b, that the effects of positional embeddedness on p(RC_{During}) is positive and equal to the effect on p(RC_{After}). The marginal effect of positional embeddedness on p(Formation), p(RC_{During}), and p(RC_{After}) are visualized in Figure 3. The opposite effects of positional embeddedness on p(Formation) and on p(RC_{During}) lead to a rejection of hypothesis 4a. The effects of positional embeddedness on p(RC_{During}) and on p(RC_{After}) correspond and also the confidence intervals overlap significantly, confirming hypothesis 4b. Figure 3 shows for p(RC_{During}) and p(RC_{After}) that as PE increases the confidence interval gets wider. This suggests that central organizations differ more in their collaboration strategies than non-central organizations. An additional analysis shows that positional embeddedness of the consortium leader reduces the likelihood of tie formation and repetition, while positional embeddedness of the consortium members enhances p(RC_{During}) and p(RC_{After}).

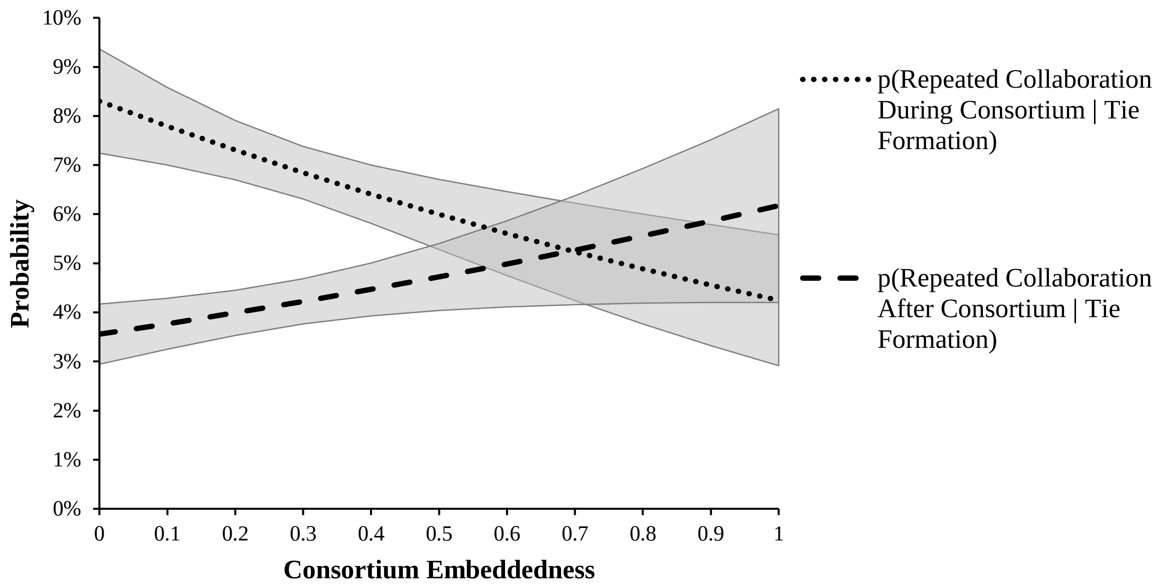
Figure 3: Marginal Effects *Positional* Embeddedness



7346 observations; † p < 0.100; * p < 0.050; ** p < 0.010; *** p < 0.001.

Finally, consortium embeddedness has a negative effect on p(RC_{During}) (Bottom half of Table 7 Cell G: -1.2%) and a positive effect on p(RC_{After}) (Cell K: +0.7%), confirming hypothesis 5. This implies that the effect of consortium embeddedness on the likelihood of repeated collaboration switches between the consortium formation and termination. Figure 4 shows the marginal effect of consortium embeddedness on $p(RC_{During})$ and $p(RC_{After})$. Although the absolute $p(RC_{During})$ is greater than $p(RC_{After})$, Figure 4 confirms the opposite directions of both consortium embeddedness effects in accordance with hypothesis 5.

Figure 4: Marginal Effects *Consortium* Embeddedness



7346 observations; † $p < 0.100$; * $p < 0.050$; ** $p < 0.010$; *** $p < 0.001$.

Table 8 shows a summary of the results.

Table 8: Summary of the Results

Hypothesis			Observation
1	The effect of past RE on p(Formation)	(Cell A) is stronger compared to	Confirmed
	the effect of past SE on p(Formation)	(Cell B) which is stronger compared to	
	the effect of past PE on p(Formation)	(Cell C).	
2a	The effect of past RE on p(Formation)	(Cell A) is positive and equal to	Partly Confirmed
2b	the effect of past RE on $p(RC_{During})$	(Cell D) which is positive and larger than	Confirmed
	the effect of past RE on $p(RC_{After})$	(Cell H).	
3a	The effect of past SE on p(Formation)	(Cell B) is positive, while	Confirmed
3b	the effect of past SE on $p(RC_{During})$	(Cell E) is negative and equal to	Confirmed
	the effect of past SE on $p(RC_{After})$	(Cell I).	
4a	The effect of past PE on p(Formation)	(Cell C) is positive and larger than	Rejected
4b	the effect of past PE on $p(RC_{During})$	(Cell F) which is positive and equal to	Confirmed
	the effect of past PE on $p(RC_{After})$	(Cell J).	
5	The effect of past CE on $p(RC_{During})$	(Cell G) is negative, while	Confirmed
	the effect of past CE on $p(RC_{After})$	(Cell K) is positive.	

3.5.1 Robustness Tests

We conducted several tests to ensure the robustness of our findings. First, we conducted robustness tests with alternative moving windows. Results obtained with one year and ten moving windows are comparable to our main results (in terms of directions of effects, significance, and marginal effects), confirming the robustness of our findings.

Second, robustness tests are conducted with one-stage models instead of a Heckman two-stage model. We applied random effects models, because fixed effects models caused severe data reductions (up to 96% of the observations). Results of these one-stage models correspond to our main findings. Also a multinomial regression on $p(RC_{During})$ and $p(RC_{After})$ shows identical results to the main model. The Heckman models are favored however, given the statistical significance of the selection effect.

Third, we conducted separate robustness tests for the seven application areas in our study. Directions of the marginal effects in the seven subsamples generally correspond to the observations in the main model, but the statistical significance of these effects fluctuated due to the small subsamples proportionally to the complex model. To further explore potential long-lasting effects of the application areas, we included the application area dummies both in the selection equation (I) and in the conditional equations (II) of our model. We complemented the instrument for tie formation with the current activity level of the consortium leader and member, in addition to the year dummies. The marginal effects of past embeddedness remained unchanged, confirming the robustness of our findings. We also conducted a robustness test in which we excluded all ties of the interview respondents from the analyses (approximately 5% of the total dataset). The results of this robustness test correspond with the main findings as well.

Fourth, we tested potential differences in past embeddedness effects on the likelihood of dyadic repeated collaboration (including the consortium leader and one member) versus multi-partner repeated collaboration (including the consortium leader and multiple members). Multi-partner repeated collaboration occur more often (early) during the consortium $p(RC_{During})$, and relatively less often after the consortium $p(RC_{After})$. Almost all past embeddedness effects correspond to the main model, but the effect of relational embeddedness on multi-partner repeated collaboration is insignificant: when multiple parties are involved, the dyadic history of the consortium leader and a focal member becomes less relevant.

Finally, we examined the potential effect of consortium success on the likelihood of repeated collaboration (Schwab & Miner, 2008). Consortium success was rated by an external committee of experts and available for a subset of 1625 of the 1715 consortia. The inclusion of consortium success in the model improves the fit to the data and consortium success has a positive statistical significant effect on the likelihood of repeated collaboration. Nevertheless, the effects of past embeddedness remained unchanged. Summarizing, the robustness of the results is confirmed by additional control variables, alternate observation periods, sub-samples, operationalization and modelling.

3.6 DISCUSSION AND CONCLUSION

This study introduces a time-sensitive theory of embeddedness in order to explore with whom and when organizations form and repeat ties through R&D consortia. The study responds to previous calls for time-sensitive theories of collaboration (e.g. Ancona et al., 2001; Zaheer et al., 1999) and elaborates embeddedness theory (e.g. Granovetter, 1985; Gulati & Gargiulo, 1999) by means of a dynamic model of the effect of past embeddedness on the formation and repetition of ties. The central message of this study is that effects of past embeddedness on the formation and repetition of ties are temporal dynamic, because over time the newly formed tie becomes embedded in the consortium. The consortium gradually gets a dual role and serves simultaneously as social structure and as social entity: (I) when a consortium leader and member enter into a joint R&D consortium, *the consortium as social structure* embeds the newly formed dyad and modifies the meaning of past embeddedness, i.e. past embeddedness effects that initially encourage tie formation differ relative to their effect on the likelihood of repeated collaboration; (II) *the consortium as social entity* simultaneously becomes embedded in the wider inter-organizational network and provides additional resources and value creation opportunities to the participating organizations. By exploring this dual role of the R&D consortium, this study furthers the development of embeddedness theory by demarcating an embeddedness theory of tie formation from an embeddedness theory of repeated collaboration.

We address the temporality of embeddedness in two ways. First, we compare the effects of past embeddedness at three distinct points in time, which is when the tie is formed through a consortium, when the repeat of a tie occurs briefly after the tie formation, and when a tie is repeated after the initial tie has been terminated. This comparison allows us to answer the question: Do past embeddedness conditions favorable for tie formation also serve the collaboration in the longer term? When do changes in past embeddedness effects occur, with the formation or termination of the consortium? We show that all investigated effects of embeddedness change over time, which justifies a demarcation of an embeddedness theory of tie formation and an embeddedness theory of repeated collaboration. What helped you find each other, can hinder follow-up projects. Second, we address the temporality of past embeddedness on the formation and repetition of ties by adding *consortium* embeddedness to the well-known types of embeddedness, i.e. relational, structural and positional embeddedness. We include consortium embeddedness in our dynamic model because of the following two reasons: a) old information and experience from past collaborations gets new meaning when two actors form a new tie through an R&D consortium. The consortium serves as an additional social structure (Breiger, 1974) where participants develop shared norms and understandings, exchange knowledge and information, and create joint value. As a consequence, the actors and their dyadic relations co-evolve and develop a new frame of reference within the consortium. b) At the same time, the consortium as social entity (Das & Teng, 2002a) gets embedded in the wider inter-organizational network that provides an additional source of knowledge and information.

The first stage of our model intends to replicate the original work of Gulati and Gargiulo (1999) and examines the effects of relational, structural and positional embeddedness on tie formation. Our results for the effects of relational and structural embeddedness on the likelihood of tie formation correspond with the findings of Gulati and Gargiulo (1999). It turns out that direct experience – relational embeddedness – has a stronger positive effect on the likelihood of tie formation than indirect information – structural embeddedness – which in turn is better than generalized information – positional embeddedness – or having no information at all. However, for positional embeddedness, Gulati and Gargiulo (1999) found a positive effect on tie formation, whereas our study shows a negative effect. Particularly a central position of the academic consortium leader seemingly constrains tie formation while positional embeddedness of the consortium member has little influence. Further research is needed to explore the specific conditions that define the direction of positional embeddedness effects on tie formation.

The second stage of our model explores the likelihood of repeated collaboration. Although there is a broad research tradition that examines embeddedness effects on tie formation, attention for embeddedness effects on the repetition and dissolution of ties emerged only recently (Dahlander & McFarland, 2013; Polidoro et al., 2011). Our study contributes to this new research line, and shows that the embeddedness conditions that encourage a consortium leader and member to form a tie, not necessarily facilitate them to repeat their collaboration. On the contrary, all four investigated embeddedness effects differ fundamentally as is shown by their change both in strength and sign over time, either with the formation of the consortium or during and after the lifespan of the consortium. The consortium is not a random environment for the dyadic relation between a consortium leader and member, but a self-selected social structure that modifies the meaning of past embeddedness. The effects of the four types of embeddedness on the likelihood of repeated collaboration are discussed in the following.

First, relational embeddedness has, relative to the other effects of past embeddedness, the strongest positive effect on the formation of ties, and repeated ties briefly after a tie is formed. Compared to having only indirect information or no information at all, a shared history of collaboration turns out to be a valuable source of direct information and experience, shared understanding and social integration that fosters the formation of new dyadic relationships.

Once a new dyad is formed, initial strangers gain their first joint experience while acquaintances expand their experience (D. Li et al., 2008). We leave it for future research to explore differences in the nature of this experience, either positive or negative, versus having no experience at all. The general view of embeddedness theory is that the *number* of prior collaborations predicts the likelihood of new tie formation and repetition (e.g. Gulati & Gargiulo, 1999), but some studies point towards the *recency* of this experience as a central factor (Baum et al., 2000; Greve et al., 2010). Our results show that, once a dyad is formed through a new consortium, the effect of past relational embeddedness evaporates between the consortium formation and termination, and older experiences from prior collaborations quickly get outweighed and overshadowed by newly gained experiences in the ongoing consortium. Our findings suggest that not the quantity of experience – i.e. the number of prior collaborations –, but the recency of the experience and the fit to the ongoing consortium which is of overriding importance for the dyad to be repeated. Exposure to recent information is more important for the repetition of ties than gaining a lot of information. This implies for embeddedness theory (e.g. Granovetter, 1985; Gulati & Gargiulo, 1999) that direct experience can be a sufficient predictor of future dyads to the extent that this experience continuously gets validated. Therefore, "Even the more or less perfect reproduction of structures is a profoundly temporal process that requires resourceful and innovative human conduct" (Sewell, 1992, p. 27), which makes relational embeddedness fundamentally dynamic.

Second, we started our discussion on the effect of structural embeddedness on the likelihood of repeated collaboration with the observation that the current literature discusses rather distinct views. Some consider structural embeddedness as indirect channels for information and referrals when direct experience is absent (Gulati & Gargiulo, 1999). Others view structural embeddedness as a source of network closure and social monitoring which results from the combination of direct and indirect ties (Coleman, 1988). Our findings demonstrate that structural embeddedness has an opposite effect for formation and repetition of ties, i.e. the effect switches from positive for the formation of ties to negative for the repetition of ties. Although common partners initially provide the focal consortium leader and focal member a safe environment to form a new collaboration, once the consortium is formed prior common partners turn into barriers for future repeats. It turns out that the initial positive effect of structural embeddedness on the likelihood of tie formation particularly occurs when a direct tie is lacking and referrals are needed to obtain some indirect information about potential partners. Conversely, the negative effect of structural embeddedness on the likelihood of repeated collaboration is because of network closure due to a combination of past indirect and direct ties. Past network closure turns out to be particularly constraining for the repetition of ties when a new tie is formed through a multi-partner R&D consortium with new third parties.

The prior third party can safeguard trustworthiness and norms of reciprocity (Obstfeld, 2005; Simmel, 1950). But these monitoring benefits do not add up easily over time. Obligations and agreements with the prior common partners (Coleman, 1988; Greve et al., 2010) might conflict with the expectations of the new common partners in the new consortium (Krackhardt, 1999). Particularly in R&D consortia, characterized by secrecy and non-disclosure agreements, conflicting obligations lurk. Thus, past structural embeddedness changes with the consortium formation from an enabler for collaboration – as source of referrals and indirect information – to a social restraint for collaboration, due to network closure and conflicting obligations.

Third, for positional embeddedness we found strongly opposing views and arguments in the existing literature. Positional embeddedness can serve as a continuing source of non-redundant information that keeps the collaboration vital (Burt, 2005; Gilsing et al., 2007), but can also become a liability due to time scarcity (Dahlander & McFarland, 2013; Polidoro et al., 2011) because attention for new tie formation comes at the expense of repeating existing ties. Our results show that positional embeddedness has an opposite effect for the formation and repetition of ties. Initially, the popularity of predominantly the academic consortium leader seems to create entry barriers that disturbs the tie formation. But once a dyadic relationship is formed, these barriers seemingly evaporate and positional embeddedness no longer hinders repetition of the tie. However, the wide confidence interval around the effect of positional embeddedness on the likelihood of repeated collaboration, suggest that organizations with a central network position can choose between two competing strategies. They can either use the generalized information that results from positional embeddedness to search for new partners or they can use the non-redundant information to repeat existing relations and keep these collaborations vital. It turns out that positional embeddedness of the consortium member mainly has a positive effect on the likelihood of repeated collaboration, while the effect is negative for the positional embeddedness of the consortium leader. From these results we infer that positional embeddedness can both enable and constrain collaboration, depending on the temporal condition (before versus after tie formation) and on the strategic decision of the involved actor. More research is needed to explore what prompts central organizations to apply these opposing strategies.

Fourth, we added consortium embeddedness to our dynamic model. In this way, we explored whether the consortium serves only as social structure (Breiger, 1974), which modifies the effects of the three former types of embeddedness on the likelihood of repeated collaboration, or that the consortium also acts as social entity (Das & Teng, 2002a), which itself becomes embedded in the wider inter-organizational network and provides consortium members access to external resources and information. Our results show opposing effects of consortium embeddedness on the likelihood of repeated collaboration during and after the consortium. A central position of the consortium turns from an initial constraint into an eventual enabler of repeated collaborations between the consortium leader and member. Initially, both the leader and the member overlap with other consortia comes with external obligations and constraints (Krackhardt, 1999). But over time, potential resource spillover from external consortia can nourish a process of mutual learning, resource exchange and joint value creation (Das & Teng, 2002a; Doz & Hamel, 1998; Doz et al., 2000) which might open up new opportunities to continue the collaboration and increases the likelihood of repeated collaboration. Ultimately, consortium embeddedness provides yet another frame of reference to the participating organizations and turns into one of the main drivers of repeated collaboration.

This study makes two central contributions to embeddedness theory (Granovetter, 1985; Gulati & Gargiulo, 1999). First, we introduce a time-sensitive theory of embeddedness and show that effects of past embeddedness on the formation of ties differ from their effect on the repetition of ties. The fact that social structure is dynamic instead of static, is not new in itself. Gulati and Gargiulo (1999) already argued: “In building new alliances, organizations also contribute to the formation of the network structure that shapes future partnerships” (p. 1449). Thus past embeddedness affects the current tie formation, and current embeddedness affects the future tie formation. What we add to this debate, is that not only the social structure changes over time, but also the *effect* of past embeddedness gets modified by the present tie formation. We demonstrate that effects of embeddedness are fundamentally dynamic: all four embeddedness effects change considerably over time, either with the formation or with the termination of the consortium. Consequently, the past embeddedness of an inter-organizational relation between a consortium leader and a member gets a substantially different meaning once they form a dyad in a new consortium. This requires agents that reproduce social structures to repeatedly make new sense of old social structures. Whereas information exposure for partner selection is the central mechanism for the explanation of tie formation (Granovetter, 1985; Gulati & Gargiulo, 1999), mechanisms that explain repeated collaboration might include mutual social integration, resource exchange and joint value creation. The observed temporal dynamics call for a separate embeddedness theory of tie formation theory and an embeddedness theory of repeated collaboration.

Second, embeddedness of the consortium as social entity fulfills a prominent role in the likelihood of repeated collaboration. By means of recently developed measurement models for two-mode networks (e.g. Borgatti & Everett, 1997; Everett & Borgatti, 2013), the study addresses Breiger’s (1974) principle of duality, manifested in a duality of organizations and consortia. The consortium embeds the inter-organizational relations between the consortium leader and the members and provides yet another frame of reference to the participants. At the same time, the consortium reproduces itself through the membership of these organizations. Particularly the temporal dynamic effects of consortium embeddedness on repeated collaborations gives guidance for interpretation: Not immediately after the formal establishment, but over time, the consortium becomes a social entity: members buy time for mutual learning, joint norm development and to settle the consortium. Between the consortium formation and termination, participants co-evolve and become socially integrated, while the consortium both serves as social structure for the participating organizations, and becomes a self-propelling social entity. Thus, the dyad between a consortium leader and a member that is embedded in the past social structure, over time becomes embedded in the current consortium, which in turn is embedded in the wider inter-organizational network. This observation adds a temporal dynamic model to Granovetter´s (1985) embeddedness theory, in which the consortium fulfills a dual role. First, the consortium serves as a social structure for the dyad between a consortium leader and member. Second, the consortium acts as a social entity that occupies a prominent role in the functioning of the social network. Hence, the study demonstrates an important duality of organizations and consortia as two social entities in innovation networks.

This study has several limitations. First, like most research on social embeddedness (e.g. Gulati & Gargiulo, 1999; Polidoro et al., 2011) we make use of secondary data which does not allow to test underlying mechanisms for embeddedness effects on the likelihood of tie formation and repetition. We assessed the embeddedness effects at three distinct points in time, and made pairwise comparisons between the time points. Additionally, we conducted several robustness tests to exclude alternative explanations. In combination with the interview results this gives guidance on the underlying mechanisms, but quantitative examination of these mechanisms is required in order to give a definitive confirmation of their workings. We leave it for future research to explore in greater detail the individual considerations of actors when and with whom to form or repeat a dyad. Such research should apply a temporal perspective to investigate the extent to which such a decision gets affected by the cumulative buildup of past experiences over time and by relational events like the termination of a prior collaboration. Research that applies such a temporal approach and monitors the relational behavior of actors over time can shed more light on the working mechanisms of embeddedness theory.

Second, some of the findings are, or can be, context-dependent. Because of the central role of the consortium leader in the R&D consortia of study, we focused on collaboration between the academic consortium leader and the representatives of the industrial firms. Industry-industry ties are not examined because they might have many different antecedents.

In addition, our analysis is restricted to consortia that were successful in their application for research funding. The analysis therefore does not include possible ties that might have been formed outside the funding scheme. Although our first-stage findings for relational and structural embeddedness effects replicate the findings of Gulati and Gargiulo (1999), the positional embeddedness effect deviates. With respect to consortium embeddedness, no prior studies were available for effect comparison. Accordingly, more research is needed that examines particularly consortium embeddedness effects in other settings to test the generalizability of our observations.

A third limitation results from the potential two-way clustering of the standard errors. The procedure developed by Kleinbaum et al. (2013) allows to examine separate clustering of standard errors for the consortium leader and the consortium member, as also applied by Dahlander and McFarland (2013). Applying this procedure, the statistical significance of several effects is reduced and some p-values even cross the 0.05-level. As discussed by Hoetker (2007), individual significance levels are not necessarily informative when marginal effects are not computed, because the implication of a one-unit increase in a variable strongly depends on the initial position on the S-curve, related to the values on all other variables in the model. Because the two-way clustering procedure does not allow for the computation of these marginal effects, we consider the original one-way clustering for the dyadic relationship between the consortium leader and member preferable.

A fourth limitation regards the shape of embeddedness effects. For parsimony reasons, we examined linear embeddedness effects. However, Uzzi (1997) discussed that some embeddedness effects can be curvilinear rather than linear. An additional test shows that, for the likelihood of tie formation, there are some diminishing returns to relational and structural embeddedness. For the likelihood of repeated collaboration, the consortium embeddedness effect is u-shaped, a natural consequence of the negative effect on repeats during the consortium and the positive effect of repeats after the consortium. Future research might give a systematic analysis of the upper end of the embeddedness curve to reveal potential mechanisms that lead to the marginal returns.

This study opens two promising directions for future research. First, we call for further exploration of the temporal dynamic perspective on embeddedness. Such a perspective allows for more detailed analysis of the explanatory mechanisms in embeddedness theory. Second, we call for applications of the two-mode networks perspective, further revealing the duality of organizations and R&D consortia. In this way, future research can discover the socialization process by which organizations and consortia give meaning to existing social structures and the replication process by which they shape new social structures.

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APPENDIX A

In this section we present a formalized representation of our model. In our research setting, dyads are always formed through R&D consortia. Tie formation at t_0 p(Formation) co-occurs with the formation of a consortium at t_0. For example, an R&D consortium of a consortium leader and five consortium members consists of five consortium leader-member dyads. Although several other dyads can be in place between the consortium members, we do not have information on that and hence ignore those dyads. Repeated collaboration is the formation of a tie at t_1, during or after the consortium, conditional (|) on the formation of a tie (i.e. consortium) at t_0. To examine the timing of repeated ties we differentiate between repeated collaboration during the consortium $p(RC_{During})$ and after the consortium $p(RC_{After})$. $p(RC_{During})$ is the likelihood of tie formation at t_1 conditional on the formation of a consortium which has not yet been terminated at t_0. $p(RC_{After})$ is the likelihood of tie formation at t_1 conditional on the formation of a consortium which *has* been terminated at t_0. Formally defined:

$$p(\text{Formation}) = p(\text{Tie formation } t_0) = p(\text{Consortium formation } t_0)$$

$$p(RC_{During}) = p(\text{Tie formation } t_1 \mid \text{Consortium formation } t_0\ (C_{formation}))$$

$$p(RC_{After}) = p(\text{Tie formation } t_1 \mid \text{Consortium termination } t_0\ (C_{termination}))$$

This research examines the temporal dynamic effects of past embeddedness (RE, SE, PE, and CE) on the likelihood of tie formation and repetition. The two central temporal events in our model are $C_{formation}$ and $C_{termination}$. We first use separate equations to test the effects of past embedded on p(Formation), $p(RC_{During})$, $p(RC_{After})$. Then we compare the different equations. These comparisons provides an answer to our research question, to what extent $C_{formation}$ and $C_{termination}$ modify the effect of past embeddedness on the formation and repetition of ties, i.e. to what extent the effects of past embeddedness are temporal dynamic. E.g. RE has a temporal dynamic effect on the likelihood of tie formation and repetition if either $C_{formation}$ or $C_{termination}$ significantly moderates the effect of RE on p(Formation t_n).

$$p(\text{Formation}) = p(\text{Tie formation } t_0) = RE + SE + PE + \quad + \text{control variables} + \varepsilon$$

$$p(RC_{During}) = p(\text{Tie formation } t_1 \mid C_{formation}) = RE + SE + PE + CE + \text{control variables} + \varepsilon$$

$$\mathbf{p(Formation\ t_n) = RE*C_{formation} + SE*C_{formation} + PE*C_{formation}}$$

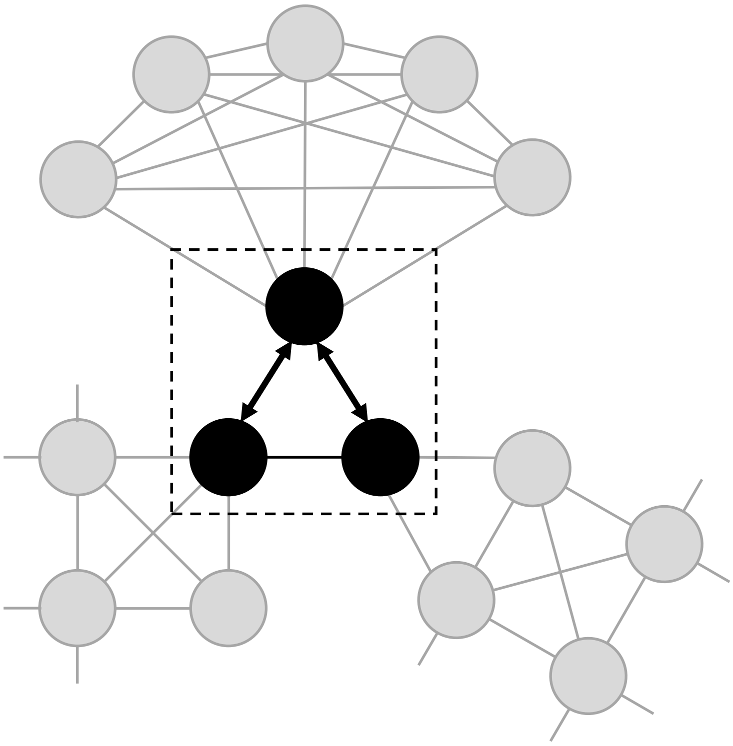
$$p(RC_{During}) = p(\text{Tie formation } t_1 \mid C_{formation}) = RE + SE + PE + CE + \text{control variables} + \varepsilon$$

$$p(RC_{After}) = p(\text{Tie formation } t_1 \mid C_{termination}) = RE + SE + PE + CE + \text{control variables} + \varepsilon$$

$$\mathbf{p(Formation\ t_n) = RE*C_{termination} + SE*C_{termination} + PE*C_{termination} + CE*C_{termination}}$$

CHAPTER 4

A CONTINGENCY MODEL OF REPEATED COLLABORATION EXPERIENCE AND INNOVATION OUTCOMES: EXPLORING THE MODERATING AND MEDIATING EFFECTS OF THE LEVEL OF PARTICIPATION IN R&D CONSORTIA



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ABSTRACT

Previous research showed mixed or even contradictory results on the relation between repeated collaboration experience and innovation success. To clarify this relation, we introduce the contingency 'level of participation', that is the extent to which consortium members mobilize their resources to contribute to the consortium activities. This study therefore provides a contingency theory of repeated collaboration in multi-partner R&D consortia, which is explored at the organization and the consortium level. We examine the contingency model by means of 544 consortium membership observations in 96 multi-partner R&D consortia, established between 1983 and 2004 in the Water sector in the Netherlands. The findings show that organizations achieve higher innovation outcomes if they continuously renew their partner portfolio, replacing old ties for new ties and engaging strongly in R&D partnerships of an intermediate lifespan. At the same time, consortia are most likely to achieve consortium success if they first attract both new and experienced consortium participants, and then encourage either the new members (two or three) or the experienced members to participate strongly. Our contingency model demonstrates the importance of the timing of actual resource inputs for innovation success. It therefore contributes to our understanding of the performance of R&D consortia.

We gratefully acknowledge useful comments from the participants of the Rotman School of Management Strategy workshop series and from the participants of the Organizational Network Research subtheme of the 29th EGOS colloquium.

Previous versions of this chapter were presented at the Rotman School of Management Strategy workshop series (Toronto, 2013), and the 29th EGOS colloquium (Montréal, 2013). A previous version of this chapter received the 2013 Andreas Al-Laham Best Paper Award of the Standing Working Group on Organizational Network Research at the 29th EGOS colloquium (Montréal, 2013).

4.1 INTRODUCTION

The importance of inter-organizational collaboration for performing complex tasks like R&D has widely been demonstrated in prior research (e.g. Doz, Olk, & Ring, 2000; Powell, Koput, & Smith-Doerr, 1996; Schilling & Phelps, 2007). What remains unclear is whether and under what conditions repeated collaboration with the same partners enhances or constrains innovation success. Although past research has shown that repeated collaboration contributes to the performance of the inter-organizational collaborations (Gulati, 1995a; Ingram & Simons, 2002; Schwab & Miner, 2008; Zollo, Reuer, & Singh, 2002), some studies provide mixed or even contradictory results and show that repeated collaboration can cause creative lock-ins, inertia, and consortium failure (e.g. Goerzen, 2007; S. X. Li & Rowley, 2002; Polidoro, Ahuja, & Mitchell, 2011; Skilton & Dooley, 2010). Moreover, research has shown that the prevalence of repeated collaboration tends to be rather low. The average number of repeated ties is reported as 0.12 (Gulati, 1995b), 0.14 (Zollo et al., 2002), and 0.20 (Polidoro et al., 2011). Obviously, actors tend to be highly selective in repeating their existing ties, even though previous research has demonstrated that repeating ties is a way to build trust and partner-specific knowledge (e.g. Gulati, 1995a, 1995b). This is argued to be particularly relevant for innovation success in R&D consortia, because of the combined high technological risks and long time horizons (Lavie, Kang, & Rosenkopf, 2010).

Often times, inconsistent or even contradictory findings are caused by unobserved contingencies. This chapter aims to identify and test one contingency, building on one of the central assumptions of network theory (Ahuja, Soda, & Zaheer, 2012; Rawlings, McFarland, Dahlander, & Wang, 2015), that ties in networks are “pipes” that facilitate flows of knowledge and resources (Borgatti & Halgin, 2011; Borgatti, Mehra, Brass, & Labianca, 2009; Podolny, 2001). We probe this assumption by introducing the contingency ‘level of participation’ of organizations that participate in R&D consortia, as resource flows only occur due to agency of the consortium members, who decided to invest in the project. They signal interests in the outcomes of an R&D project by mobilizing resources, whereas refraining from such signals, means that they rather prefer a more distant observer role. This contingency enhances an assessment of the sensitivity of the relation between repeated collaboration experience in R&D consortia and innovation success. We argue that the level of participation of consortium members, which is measured as the resource inputs mobilized by the individual consortium members, should enhance our understanding of the mixed and sometimes contrasting results of former research on repeated collaboration. Our central thesis is that organizations with moderate levels of repeated collaboration experience are more likely to mobilize their resources and thereby increase the innovation success (mediation), and if they do, these organizations are more likely to benefit from their resource contributions (moderation) compared to organizations with low or high levels of repeated collaboration experience.

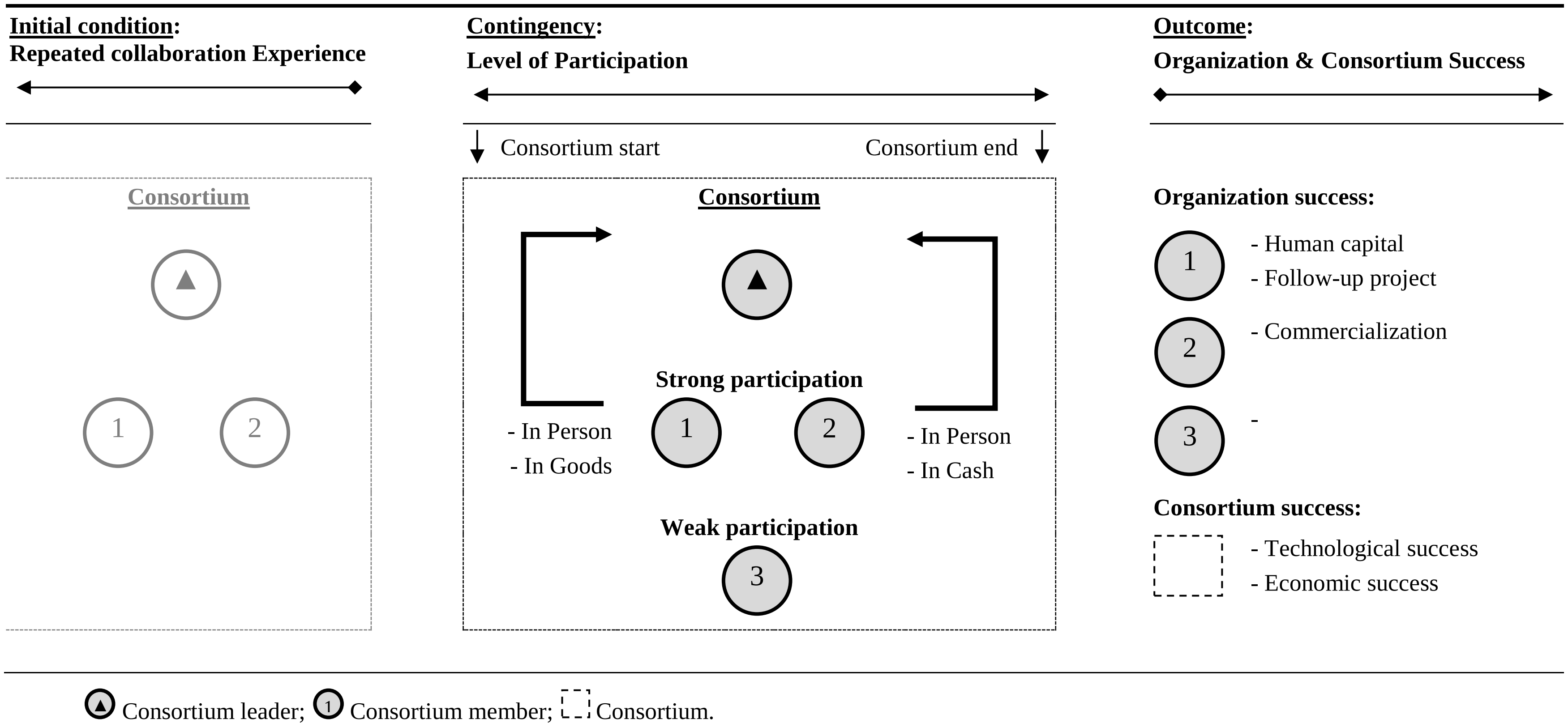
In addition, we compare the effects of repeated collaboration and the level of participation on innovation success at two levels of analysis: the organizations that are members of the consortium, and the consortium itself. This distinction of multiple levels of analysis is motivated by the fact that collaboration in R&D consortia serves at minimum two goals, that of the individual organization and the collective consortium (Cohen & Levinthal, 1989; Jones, Hesterly, Fladmoe-Lindquist, & Borgatti, 1998). These goals are not necessarily congruent, or mutually reinforcing, they can be contradictory as well, which requires an analyses of both the individual organization represented by consortium members and of the consortium. Therefore examining both organization and consortium success adds considerable refinement to our understanding of the functioning of R&D consortia. The research question is: *To what extent is organization and consortium innovation success related to repeated collaboration experience, and to what extent is this relation moderated and/or mediated by the level of participation of consortium members?*

Data collection took place by means of a document study on R&D consortia in the Water sector in the Netherlands. To test the hypotheses, we analyzed 544 consortium members in 96 multi-partner R&D consortia, established between 1983 and 2004. In addition, we complemented the document analysis with 51 interviews with consortium leaders and members.

4.2 A Contingency Theory of Repeated Ties

The study contributes to the growing literature that conducts moderated mediation analyses to open the black box of R&D collaborations (Andreeva & Kianto, 2011; Engelen & Brettel, 2012; Spanos, 2012). We identify optima and liabilities of repeated collaboration conditional upon certain levels of participation. Our contingency model of inter-organizational collaboration in R&D consortia defines repeated collaboration experience as an initial condition that has been accumulated before the consortium start, the level of participation as contingency, and innovation outcome as measures for organization and consortium success. Figure 1 displays the contingency model at multiple levels: the individual organization which is a member of the R&D consortium and the R&D consortium. We argue that repeated collaboration experience gained prior to the consortium influences the level of participation in the consortium, which in turn affects the outcome in terms of organization and consortium success. The level of participation and the innovation outcome can take various forms as indicated in Figure 1. In the following, we will first explain the three central concepts – innovation outcome, repeated collaboration experience, and level of participation – at both levels of analysis. Second, we provide the theoretical arguments to justify our contingency model, at the level of the

Figure 1: Contingency Model



organization as well as on the level of the consortium. Hypotheses 1-4*a* address the organization level and hypotheses 1-4*b* regard the consortium level.

4.2.1 Innovation Outcome

Innovation depends more and more on inter-organizational collaboration because of growing specialization of companies, and the wide dispersion of resources and skills over different organizations (Chen & Yun, 2008; Powell et al., 1996; Schilling & Phelps, 2007). In order to share risks, resources and skills, organizations can form R&D consortia. An R&D consortium is a social entity that aligns joint activities to pursue both collective and individual goals and outcomes (Das & Teng, 2002; Oerlemans & Meeus, 2009). Despite the recognition that cooperation is always accompanied by competition (Axelrod, 1997; Axelrod & Hamilton, 1981), most literature fails to address the fact that individual members and the R&D consortium as different entities could have competing and complementary goals. Consequently, a firm's incentive to participate in an R&D consortium can be twofold, namely to achieve the collective goal (e.g. new product development), and to achieve the individual goal as a consortium partner (e.g. to obtain and exploit knowledge of partners) (Cohen & Levinthal, 1989; Jones et al., 1998). For that reason, an adequate outcome indicator for consortium membership includes both levels of analysis: the collective and the individual goal achievement (Provan & Milward, 2001; Richard, Devinney, Yip, & Johnson, 2009). Goal accomplishment – generating innovation outcomes – at both levels can be mutually reinforcing, co-existing or provide a tension between the collective and individual level. Although this potential tension is often discussed for dyadic alliances (e.g. Khanna, 1998), empirical studies on goal accomplishment on both levels are rare, particularly for multi-partner R&D consortia. Therefore we examine in this study both the probability of consortium success (achievement of the collective goal) and the probability of organization success (organization level benefits of the consortium membership). Organization success therefore refers not to the overall performance of an organization, but to the specific gains from its participation in a consortium.

4.2.2 Repeated Collaboration Experience

As R&D consortia often are characterized by long time-horizons and high interdependencies (Das & Teng, 2002), selection of reliable and complementary partners is essential for organization and consortium success (Emden, Calantone, & Droge, 2006; Vissa, 2011). Previous studies have emphasized the importance of prior experience for successful R&D partnering (e.g. S. X. Li & Rowley, 2002; Mitsuhashi & Greve, 2009; Powell et al., 1996). To get full understanding of such experience effects, we distinguish "shared" repeated collaboration experiences that requires prior direct collaboration between the focal partners, and "generic" collaboration experience that stems from collaboration in the inter-organizational network with other than the focal partners. Although some studies suggest that generic collaboration experience can improve the abilities for advantageous partnering and collaboration (e.g. Ahuja et al., 2012; Mitsuhashi & Greve, 2009; Powell et al., 1996), empirical studies show contradictory results (Tzabbar, Aharonson, & Amburgey, 2013; Zollo et al., 2002). Direct experience on the other hand provides reliable first-hand information for partnering (Ahuja, 2000; Granovetter, 1985). Therefore, this research controls for generic collaboration experiences, but focuses on the effects of partner-specific repeated collaboration experiences.

At the organization level, repeated collaboration experience is operationally defined as the joint participation of the consortium leader and member organizations in previous consortia. Previous research has shown that dyads embedded in prior direct interactions differ from 'new' arm's-length ties, because the involved agents had the opportunity to acquire accumulated experience, joint knowledge, trust, and shared ways of evaluating (e.g. Gulati & Gargiulo, 1999; Uzzi, 1997). Consortium members can vary in their degree of repeated collaboration experience with the consortium leader. This variance at the organization level adds up to consortium level variance in the joint pool of repeated collaboration experience: the consortium may comprise of merely inexperienced members, all more or less experienced members or a combination of inexperienced and experienced members. At the consortium level, repeated collaboration experience is operationally defined as the ratio of new and experienced members. The repeated collaboration ratio can have important implication for the functioning of the consortium, as experienced members can provide stability and routines to the consortium wheareas new members can add non-redundant information (Das & Teng, 2002; Jones et al., 1998; Ring & Ven, 1994).

4.2.3 Level of Participation

"Perhaps the most common mechanism for explaining consequences of social network variables is some form of direct transmission from node to node" (Borgatti et al., 2009, p. 894). In social network theory, ties are often times considered as "pipes" which facilitate flows of knowledge and resources between the involved actors (Borgatti & Halgin, 2011; Podolny, 2001). However, usually the "pipes" and not the actual flows are measured in social network research (Ahuja et al., 2012). For an exception, see the recent study by Rawlings et al. (2015), which explored the extent to which collaborations among researchers of Stanford University resulted in actual knowledge flows. We extend this new research line and examine resource flows between university and industry representatives in multi-partner R&D consortia, and we test their performance implications.

The level of participation is operationally defined as the extent to which consortium members contribute to the activities in the consortium. Organizations in R&D consortia can engage in different ways, either by participating strongly in the co-development of new knowledge or by weak or even cautious participation aimed at the individual assimilation of existing knowledge (Cohen & Levinthal, 1989). We measure the level of participation dichotomously as either having no resource input mobilized, or as having distinct types of resources mobilized. The dichotomous categories of levels of participation are indicative of either strong or weak participation in the R&D consortium. Organizations that participate strongly (strong participants) and mobilize their resources signal their interest and can make a justified claim on a stake in the innovation outcomes of the R&D consortium. Refraining from such inputs on the other hand boils down to weak participation (weak participants), but these organizations can still provide critical mass, legitimacy, and monitoring abilities to the consortium (Das & Teng, 2002; Human & Provan, 2000).

The level of participation at the organization level differs from the level of participation at the consortium level. While an individual organization can engage in distinct levels of participation, the consortium level of participation aggregates the levels of participation of member organizations. At the consortium level, we operationally define the level of participation as the number of members that participates strongly in the consortium. Obviously, the fashion in which partners participate has important implications for the innovation success of the organization and the consortium. Rothwell (1986), Von Hippel (1976, 1988), and the triple helix literature (Etzkowitz & Leydesdorff, 2000) report higher innovation outcomes when users of the potential innovation participate strongly in the innovation process. Both the consortium as a whole and the individual member organization can benefit from such contributions (Das & Teng, 2002; Jones et al., 1998; Mothe & Quélin, 2000). A lack of strongly participating members can hamper the organizing capacity of the consortium, while an overload of strongly participating organizations can become a liability, accompanied by goal ambiguity and management issues.

In this study, we examine to what extent the level of participation moderates and mediates the relation between repeated collaboration experience and innovation success. We will first discuss these effects for the organization level and then for the consortium level. Although research on multi-partner consortia has expanded the last two decades (e.g. Branstetter & Sakakibara, 2002; Das & Teng, 2002; Doz & Hamel, 1998; Doz et al., 2000; Gomes-Casseres, 1996), little attention has been devoted to disentangling both levels of analysis in one study. Our approach contributes to the understanding of the functioning of R&D consortia (Lazega, Jourda, Mounier, & Stofer, 2008), because the explanatory mechanisms at both levels can be fundamentally different. Organizational actions that contribute to organization success, do not necessarily enhance the consortium success and vice-versa (Cohen & Levinthal, 1989; Jones et al., 1998; Provan & Milward, 2001), e.g. weak participants are less likely to achieve organization success compared to strong participants (Lavie, Lechner, & Singh, 2007), but can still contribute to the consortium legitimacy and performance (Das & Teng, 2002; Human & Provan, 2000). Moreover, variance in repeated collaboration experience and in the level of participation is more complicated at the consortium level compared to the organization level. Whereas an individual organization can be inexperienced or more experienced, a consortium can include a configuration of all inexperienced organizations, all experienced organizations, or a mixture of inexperienced and experienced organizations.

4.2.4 Contingency Model: Organization Level

In the following, we discuss the three hypothesized effects of repeated collaboration experience on innovation success: the direct effect, the mediated effect and the moderated effect. First, we discuss the direct effect of repeated collaboration experience on innovation outcomes, which captures the extent to which organizations that accumulated mutual experience prior to the start of a new consortium are more likely to benefit in terms of innovation outcomes. Second, we address the potential mediating effect of the level of participation, which refers to the extent to which organizations with repeated collaboration experience are more likely to participate strongly, and thereby increase the innovation success. Third, we discuss the moderating effect of the level of participation, which regards the extent to which organizations that combine repeated collaboration experience with strong participation (i.e. resource mobilization) increase their probability of innovation success.

Direct Effect of Repeated Collaboration Experience. At the organization level, repeated collaboration experience entails the joint participation of the consortium leader and member organizations in previous consortia. Variance in collaboration history is an important predictor of the success probabilities of individual organizations (Lavie et al., 2007). Previous research has demonstrated that repeated collaboration experience, achieved through direct collaborations with a partner, provides the opportunity to evaluate the partner's capabilities as well as the partner's trustworthiness (Gulati, 1995a, 1995b; S. X. Li & Rowley, 2002; Rowley, Greve, Rao, Baum, & Shipilov, 2005; Schwab & Miner, 2008; Tzabbar et al., 2013). This is particularly important in R&D consortia, where the technological risks are relatively high (Lavie et al., 2010). Organizations can use these partner-specific insights to select the most advantageous partnering opportunities.

There is also a downside to prior collaborations (D. Li, Eden, Hitt, & Ireland, 2008), as repeated collaboration experiences are not without constraints. Repeated collaborations with familiar partners can evaporate the innovative capacity due to creative lock-ins and inertia that increase the risk of consortium failure (Goerzen, 2007; S. X. Li & Rowley, 2002; Polidoro et al., 2011; Skilton & Dooley, 2010; Zheng & Yang, 2015). We build on the recent work of Zheng and Yang (2015) who argue that the potential benefits of repeated collaboration experience (e.g. the information about the partner's capabilities, the opportunity to align the project execution in the consortium) and the constraints of repeated collaboration experience (lock-ins, reduced creativity), do not come at the same pace. Organizations participating for the first time are likely to experience information benefits, while lock-in constraints are more likely to arise over multiple joint consortia. In line with this, an interviewee argued: "An advantage [of repeated collaboration experience] is that you know each other very well. You know what happened in previous projects. […] a potential disadvantage is that you can get locked-in at a given moment. Attracting new partners can be nice sometimes." Therefore, we expect that the probability of individual organization success is enhanced by repeated collaboration experience, until a threshold is reached and then decreases.

Hypothesis 1a. Repeated collaboration experience has an inverted u-shaped relation with the probability of organization success.

Mediating Effect of the Level of Participation. Many researchers argued that repeated collaboration experience can provide information advantages (e.g. Gulati, 1995a, 1995b; Schwab & Miner, 2008) and joint routines (e.g. Tzabbar et al., 2013; Zheng & Yang, 2015; Zollo et al., 2002), which in turn increase the probability of innovation success. However, the underlying premise that these collaborations induce actual resource mobilization to create innovation outcomes, has been left virtually unexplored (Ahuja et al., 2012; Rawlings et al., 2015). We argue that the probability that organizations mobilize their resources is a function of their repeated collaboration experience. The information advantages and joint routines that these organizations acquire through repeated collaborations enable them to make well-informed and targeted contributions to the consortium, and if they make such contributions, they signal an interest in the eventual outcomes and can make a justified claim on a stake in the innovation outcomes of the consortium. Thus, repeated collaboration experience can have a direct effect on the probability of innovation success, but it can also increase the probability that an organization makes strong contributions to the consortium, which in turn enhances the probability of innovation success.

Newcomers that enter the consortium for the first time might be inclined to employ a wait-and-see strategy, because they had no prior opportunities to monitor and evaluate the consortium or to collecting information about mutual opportunities (Doz et al., 2000; Gulati, 1995b; Ring & Ven, 1994). Organizations that repeat their collaboration with the consortium leader are more likely to participate strongly and allocate resources to the collaboration (Sorenson & Waguespack, 2006), because they are better able to match the consortium goal and their own interests (Mothe & Quélin, 2000) and because they have achieved partner-specific experience (Zollo et al., 2002) providing them insights to identify opportunities for strong participation. One interviewee argued for instance: "Now [in the second project] I have the feeling that I can contribute more, because in the beginning [the first project] I had to get used to this type of research. I was perhaps… not reserved, but hesitant […] in the sense of wait and see what happens […]. This differs from the more focused contribution to the [innovation outcome] I have made in the second project". Thus repeated collaboration experience might affect the collaboration process through the "activation" of the consortium members. However, too many repeats can reduce the potential for strong participation. Organizations that repeat their collaborations in multiple consortia can drift into routine collaborations that are driven by inertia (S. X. Li & Rowley, 2002; Sydow, Schreyögg, & Koch, 2009), rather than active selection of advantageous partnering opportunities. After multiple repeats, routine collaborations might impede organizations to recombine their mutual resources into new inventions that meet the dynamic requirements of their complex environments (Goerzen, 2007). Relations are likely to become obsolete and exhausted, and new entrants with non-redundant information become required for novel contributions (Skilton & Dooley, 2010; Uzzi, 1997). Therefore, the probability that organizations make strong contributions to the consortium is most likely to increase and then decrease over time with the repeated collaboration frequency.

Hypothesis 2a: Repeated collaboration experience has an inverted u-shaped relation with the level of participation of the organization.

In the previous section we discussed the effect of repeated collaboration experience on the level of participation. In this section, we discuss the effect of the level of participation on the probability of organization success. We conjecture that organizations that participate strongly in the R&D consortium have a higher probability of innovation success compared to organizations that participate weakly, because strong participants both contribute to the innovation outcome and signal interest, and therefore they can claim a stake in this outcome. Organizations in R&D consortia can engage in consortia in different ways, either strongly, mobilizing their resource to contributing to the collective goal, or weakly, mainly monitoring activities and outcomes of the R&D consortium (Cohen & Levinthal, 1989). Organizations that participate strongly in the consortium "[…] can better shape its agenda […] establish superior access to technical and market information […] generate more innovative applications based on jointly developed technologies and […] build supporting process- and product-related routines and capabilities that increase the likelihood of successful commercialization" (Lavie et al., 2007, pp. 581-582). Investments in the R&D consortium have strong signaling value (Ozmel, Reuer, & Gulati, 2013). One interviewee stated: "[This organization] contributed a lot. I think they invested about 100.000 Euros in the project. […] they also allowed the PhD student [executive researcher] to sit at [their company] for two days per week, so that he basically could see the real development of this. […] immediately after the PhD project ended, or maybe before, he was offered a contract. That went very smoothly." Another respondent argued: "If a company co-supervises the PhD student [i.e. makes in person contributions], it means they are really interested in [the innovation outcome of the consortium] and in the person that is knowledgeable about this [innovation]." Given that consortium members collectively monitor "the pooling and redistribution of resources" (Das & Teng, 2002, pp. 451-452), organizations that make strong contributions are likely to claim their fair share in the achieved organization success. Ring and Ven (1994) refer to indebtedness of the weak participants to the strong participants: The disproportionate contributions of the strong participants "[…] result in social norms of obligations for the future […]" (p. 94) vis a vis the weak participants. Of course, weak participants can also benefit from their membership, and assimilating knowledge and other intangible goods that spillover to them (Cohen & Levinthal, 1989). A consortium leader argued for instance: "We have concluded an agreement [with a weakly participating consortium member], because we knew that they would never use our product. They just wanted to have our ideas. They paid us to attend our weekly progress meetings." But organizations that participate strongly in the consortium and mobilize their resources, contribute more to the innovation success and will therefore make a claim on this success (Mothe & Quélin, 2000).

Hypothesis 3a. The level of participation increases the probability of organization success.

Moderating Effect of the Level of Participation. So far we discussed the direct and the mediated effect of repeated collaboration experience on the probability of innovation outcomes. The direct effect is rooted in information advantages that enhance organizations' selection and repetition of the most favorable partnerships (Doz, 1996; Gulati, 1995b; S. X. Li & Rowley, 2002; Mitsuhashi & Greve, 2009). The mediated effect results from accumulated routines and insights that enable organizations to participate strongly in the consortium (Sorenson & Waguespack, 2006; Zheng & Yang, 2015), which in turn increases the probability of innovation outcomes (Lavie et al., 2007; Mothe & Quélin, 2000). A third, yet undiscussed path includes organizations that combine repeated collaboration experience with high levels of participation. This causal path pertains to a moderating effect of the level of participation on the relation between repeated collaboration experience and the probability of innovation outcomes. The underlying reasoning is twofold. First, repeated collaboration can provide organizations partner-specific experience and routines (S. X. Li & Rowley, 2002; Zollo et al., 2002), but organizations that mobilize resources are more likely to reap the rents of their accumulated experiences, compared to organizations that do not effectuate their experiences and participate weakly in the consortium (Mothe & Quélin, 2000). Second, organizations that participate strongly can increase their probability of success, but not all organizations will benefit to the same extent from their resource contributions. Experienced organizations can make better informed and more targeted contributions to the consortium than inexperienced organizations (Emden et al., 2006; Mitsuhashi & Greve, 2009; Vissa, 2011; Zheng & Yang, 2015) and hence stronger claims on the innovation outcome. Thus, organizations that participate strongly in the consortium are more likely to benefit from their contributions if they have repeated collaboration experience, compared to inexperienced organizations that mobilize their resources. At the same time, organizations with repeated collaboration experience that participate strongly in the consortium have a higher probability of innovation success compared to experienced organizations that participate weakly.

Hypothesis 4a. The relation between repeated collaboration experience and the probability of organization success is stronger for a high level of participation relative to a low level participation.

4.2.5 Contingency Model: Consortium Level

In the following, we first discuss the direct effect of repeated collaboration experience on the probability of consortium success, and then the mediation and moderation of this relation by the level of participation.

Direct Effect of Repeated Collaboration Experience. At the consortium level, repeated collaboration experience concerns the ratio of new and experienced members. Ratio and diversity scores are common ways to express the composition of a consortium or group of organizations (e.g. Branstetter & Sakakibara, 2002; Rowley et al., 2005). Prior research has emphasized the importance of the mutual experience for the functioning of a consortium (e.g. Gomes-Casseres, 1996; Hoang & Rothaermel, 2005; Ring, Doz, & Olk, 2005). Jones et al. (1998) for instance argued that consortia with high levels of repeated collaboration experience are more likely to pursue collective goals, while consortium members that had little prior interactions are more likely to pursue their individual advantages. Repeated collaboration experiences can provide mutual understanding and can increase the opportunity to align the consortium goal and execution to the consortium members' capabilities and interests (Ring et al., 2005). Joint routines, mutual understanding, and collective ways of monitoring the functioning of the consortium can increase the probability of consortium success (Das & Teng, 2002; Hoang & Rothaermel, 2005). However, this is a non-linear relation, repeated collaboration experience can increase the probability of consortium success until a certain threshold, after which the probability of consortium success starts to decrease. This decrease is due to creative lock-ins, a lack of non-redundant information, and inertia (D. Li et al., 2008; Skilton & Dooley, 2010; Zheng & Yang, 2015), or “knowledge ossification [and] complacency effects” (Hoang & Rothaermel, 2005, p. 335). Consortia that include a mixture of both experienced members who provide stability and routines to the consortium, and new members who add non-redundant information to the consortium, are believed to have the highest probability of success.

Hypothesis 1b. Repeated collaboration experience has an inverted u-shaped relation with the probability of consortium success.

Mediating Effect of the Level of Participation. One way in which repeated collaboration experience can increase the probability of innovation outcomes is by activating the consortium members, who in turn contribute to the innovation outcome of the consortium. At the consortium level, the level of participation refers to the number of organizations that participate strongly in the consortium. However, it is not necessarily beneficial if all members mobilize their resources. The sheer presence of a significant number of – be it weakly participating - organizations enhances the consortium legitimacy (Human & Provan, 2000), while an overload of strong participants can become a liability, accompanied by goal ambiguity and management issues. Activating a balanced number of strong participants is an important management task of the consortium leader (Ring et al., 2005), but not every consortium leader will be equally successful in achieving an optimal level of participation of the consortium members. The probability that the consortium achieves such an optimal mixture of strong and weak participants, i.e. that the resource mobilization corresponds with the consortium requirements, is believed to increase with the repeated collaboration experience of the consortium leader and members (Mitsuhashi & Greve, 2009; Ring & Ven, 1994; Tzabbar et al., 2013; Zollo et al., 2002). Consortia that are socially embedded in prior collaborations can develop mutual routines for resource exchange (Zheng & Yang, 2015), and need less time to explore common grounds and align mutual interests, instead these consortia can directly focus on the activity and resource contributions of consortium members (Ring et al., 2005). Therefore, consortia with higher levels of repeated collaboration experience might be better at resource mobilization. One of the interviewees stated for instance: “From the previous project, we knew where the deficiencies were in the consortium. [In the second project] we have strengthened this part and we have built a very strong consortium. We have designed the proposal together, [...] it was a very good proposal, because [...] from the experience of that first project we knew exactly what things still needed to be done." However, consortia that only include experienced members and do not attract any new members, might lack access to non-redundant information and resources (Uzzi, 1997), and can get locked into fixed patterns of resource contributions that do not correspond with current consortium requirements (Hoang & Rothaermel, 2005; Sorenson & Waguespack, 2006; Sydow et al., 2009). Therefore, consortia with a moderate level of repeated collaboration experience, i.e. both new and experienced members, are most likely to achieve an optimal level of participation. We refer to an 'optimal' level of participation and not the absolute level of participation, because a larger number of strong participants not always increases the probability of consortium success, as further explained in the next section.

Hypothesis 2b: Repeated collaboration experience has an inverted u-shaped relation with the level of participation in the consortium.

Previous research has demonstrated that the probability of innovation success is higher when consortium members – in this study mostly technology developers and users – participate strongly in the innovation process (e.g. Etzkowitz & Leydesdorff, 2000; Prahalad & Ramaswamy, 2004; Rothwell, 1986; Von Hippel, 1976, 1988). Although, not all consortium members have to participate strongly and to mobilize their resources in order to contribute to the consortium. An interviewee stated: "In case of a consortium with four or five member organizations, probably only one or two will make strong contributions, while the others are just members of the user committee that meets twice a year." Weak participants determine the critical mass of the consortium, increase the consortium legitimacy, and provide monitoring abilities to the consortium (Das & Teng, 2002; Human & Provan, 2000). In addition, weak participants can be a safeguard against information redundancy and can create future partnering opportunities (Uzzi, 1997). Strong participants on the other hand, contribute to the achievement of innovation outcomes by making resources available to the consortium. Relative to the organization level contingency model, at the consortium level, the core issue shifts to the mixture of strong and weak participants that provides the best composition for consortium success. Given the consortium size, particularly the share of strong participants is decisive for the consortium success. Consortia with too few strong participants might lack organizing capacity and resources to achieve innovation outcomes, but consortia with too many strong participants can face all kinds of management issues, like goal ambiguity and rivalry amongst consortia members (Axelrod, 1997; Axelrod & Hamilton, 1981; Jones et al., 1998; Ring et al., 2005) and commitment issues. An interviewee argued: "Often times it is most convenient when one of the consortium members takes the lead in the development and marketing of [the innovation outcome]. That is because of economic reasons and ownership, commitment to the product". Therefore, we expect that a consortium is most likely to be successful when the share of strong participants is moderate rather than low or high:

Hypothesis 3b. The level of participation in a consortium has an inverted u-shaped relation with the probability of consortium success.

Moderating Effect of the Level of Participation. In the previous section we discussed the extent to which level of participation in a consortium can mediate the relation between repeated collaboration experience and the probability of consortium success, i.e. the level of repeated collaboration experience influences the probability that a consortium achieves an optimal level of participation, which in turn increases the probability of consortium success. But the level of participation can also moderate the effect of repeated collaboration experience on the probability of consortium success. We argue that consortia with an optimal level of participation are most likely to benefit from resources that are mobilized by these actors, if the strong participants include a mixture of both new and experienced members. At the same time, consortia with such a mixture of new and experienced members benefit most from this composition when the involved actors participate strongly in the consortium and mobilize their resources. We derived both arguments from an assumption that pertains to the different contributions of consortium member given their collaboration experience. Inexperienced members supposedly contribute non-redundant information (Uzzi, 1997), whereas experienced members provide joint routines, mutual understanding, stability, and value to the consortium (Hoang & Rothaermel, 2005) only if the consortium member actively mobilizes its resources (Ahuja et al., 2012; Borgatti et al., 2009; Rawlings et al., 2015). Thus, the extent to which the pool of repeated collaboration experiences is utilized to achieve consortium success depends on the level of participation in the consortium, while repeated collaboration experience of passive members goes unnoticed and will not encourage the probability of consortium success.

Hypothesis 4b. The relation between repeated collaboration experience and the probability of consortium success is stronger for a high level of participation relative to a low level participation.

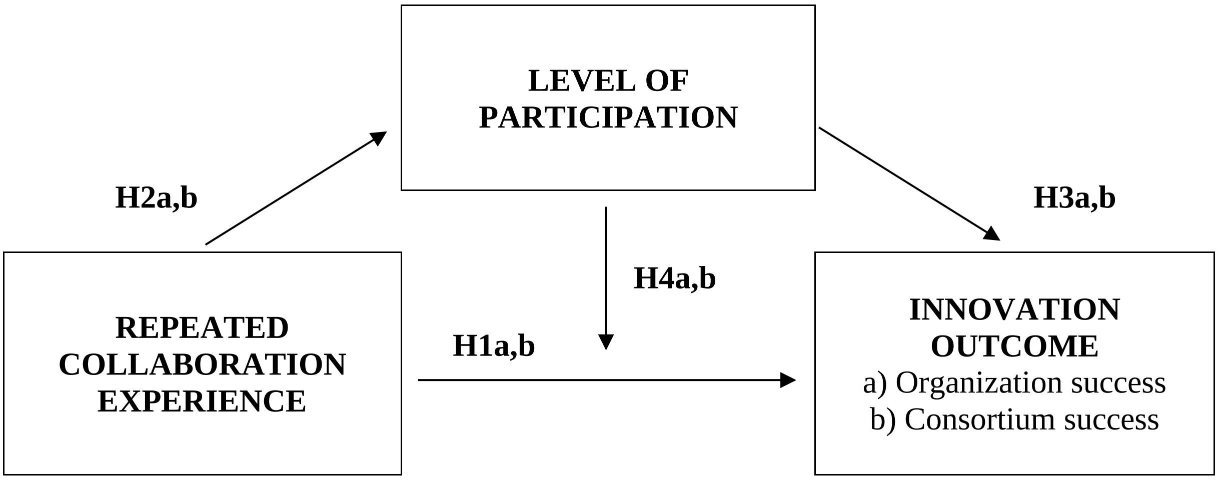
Figure 2 shows the conceptual model at both levels of analysis.

4.3 Methodology

4.3.1 Research Setting

In 2011, the Dutch Government announced a new innovation policy in order to stimulate 9 so called "Top-sectors" to maintain or achieve a world-leading position through science industry collaboration (Kamerstukken 2010/11 32 637 nr. 1). One of these sectors is the Water

Figure 2: Conceptual Model



[a] Control variables: start year; subfield; allocated funding; consortium size; consortium leader experience; member experience; partner experience; joint member experience.
[b] 544 observations on 96 consortia.
[c] Hypotheses: H.a Organization level; H.b Consortium level.
[d] Hypotheses: H1 Direct effect; H2 & H3 Mediated effect; H4 Moderated effect.

sector in the Netherlands, consisting of the subfield Maritime technology, Delta technology, and Water technology. With respect to the Water sector, the policy itself is not that pioneering: due to the fact that a large part of the Netherlands is located below the sea level, Dutch water research has a long history and is internationally renowned (Karstens et al., 2011; Maritiem Cluster in de Topsector Water, 2011). Therefore, the Water sector in the Netherlands is an excellent empirical setting to study repeated collaboration and temporary R&D consortia (Levering, Ligthart, Noorderhaven, & Oerlemans, 2013). From 1983 until 2004, a funding agency that facilitates Dutch university-industry collaboration has funded 100 multi-partner R&D consortia in the water sector. Due to missing values on 4 consortia, the sample includes a total of 96 consortia which represent 544 individual consortium memberships. These R&D consortia consist of a consortium leader, connected to one of the Dutch Universities, and a user committee of organizations (consortium members), like Deltares, Shell, the Royal Navy or Witteveen+Bos. Successful consortia for example developed a model for the three-dimensional modelling of non-linear surface waves, a design for aerobic granular sludge reactors in water treatment plants, and a world leading simulation program for hydrodynamic wave loading on floating and moored constructions in steep waves. These kind of R&D consortia provide a great opportunity to investigate the influence of repeated collaboration experience and the level of participation on innovation success.

4.3.2 Data Collection

Data collection took place by means of a document study. To test the hypotheses, we analyzed 544 consortium members in 96 multi-partner R&D consortia, established between 1983 and 2004. The same agency that funds these R&D consortia also performs an evaluation of all consortia at 5 years and/or 10 years after the consortium start. The funding agency publishes these evaluations in so-called utilization reports that provide information on the consortium leader, partner organizations, start year, end year, allocated funding and consortium success. Collaboration beyond the boundaries of this funding scheme is not taken into consideration. Furthermore, right censoring is likely to be present, as many consortia achieve innovation outcomes more than 10 years after the consortium start, and are therefore not mentioned in the reports. In addition, in order to achieve insight in the level of participation of the involved organizations, we examined the acknowledgements in PhD-theses and publications that resulted from these consortia. We analyzed in total 168 utilization reports, 96 PhD-theses and 104 additional publications, providing on average 3.538 documents per consortium. To control for variance in researcher quality, we collected additional data on 914 publications of the executive researchers. Finally, to gain qualitative insights in the functioning of the R&D consortia, we conducted 51 interviews with stratified sampled respondents (13 consortium leaders and 38 consortium members; successful and unsuccessful; from all three subfields in the Water sector; with and without repeated collaboration experience).

4.3.3 Modeling

This study applies two separate analyses to examine innovation success at the organization level and at the consortium level. At the organization level, the consortium membership of the individual organization is the unit of analysis and observations are nested in consortia. We adjust for consortium level clustering of error terms. We achieve similar results with models that adjust for two-way clustering of error terms, for the consortium leader and member (Kleinbaum, Stuart, & Tushman, 2013). At the consortium level, the consortium is the unit of analysis and observations are nested in the R&D portfolio of the consortium leader. As the dependent variables at both levels – organization success and consortium success – are dichotomous, we applied multilevel mixed effects regression analyses with a logistic regression transformation in order to research the probability of organization and consortium success. We discuss alternative model specifications to control for the clustering of the error terms (e.g. fixed effects; heterogeneous choice model) in the robustness test section. We conducted moderated mediation analyses (Preacher, Rucker, & Hayes, 2007) to test our contingency model, with a dual effect – moderation and mediation – of the level of participation on the relation between repeated collaboration experience and innovation outcomes. Moreover, we estimated average marginal effects, as in logistic regression analysis the effects of the independent variables depend on all other variables in the model (Hoetker, 2007). This allows us to present intuitive graphical representations of the observed effects, which are particularly recommended for interaction effects in non-linear models (Hoetker, 2007; Karaca-Mandic, Norton, & Dowd, 2012).

4.3.4 Measures

Outcome. The dependent variable of this study regards the innovation outcome, measured by the organization success of consortium member and the consortium success. Organization success includes 3 dimensions: (I) the achievement of human capital (e.g. PhD Employment); (II) the achievement of a follow-up project with a strong utilization value for the organization; and (III) commercialization of the consortium results (e.g. the achievement of patents, exploitation licenses, implementation of the consortium results). If an organization has reported one or more of these achievements, we coded organization success as (1). If an organization did not report any scores on these indicators, we coded organization success as (0). It must be noted that the announcement of such organization success was encouraged by the funding agency, which makes the absence of outcomes a significant and meaningful value. An interviewee stated: “There are three reasons to participate in these consortia: firstly, if you have an issue that you want to elaborate in a scientific manner, that is to achieve substantial value. Secondly, to strengthen your ties with the university, update your knowledge and engage in future research. Thirdly, to scout potential future employees.”

We derive the values of ‘consortium success’ from the utilization score of the consortium, rated by an external committee of specialists that was appointed by the funding agency. Two criteria of these external evaluations are particularly informative for our study and give an indication of the tangible innovation outcomes of the consortium, namely (I) product development, and (II) income achievement by the R&D consortium. Consortium success is coded as high (1) if the consortium scored at least an average of 2 on the utilization scale from 0 to 3, and coded as low (0) if it scored an average below 2. Correspondingly, the individual dimensions product and income are coded as high (1) if the consortium scored at least a 2 on the dimension, and coded low (0) if it scored below 2, in order to allow subtests for these dimensions.

Repeated Collaboration Experience. We define repeated collaboration experience as the number of joint participations of the consortium leader and member organizations in previous consortia. At the organization level repeated collaboration experience is calculated as the number of previous consortia that include both the focal organization and the consortium leader. At the consortium level, repeated collaboration experience is calculated as a ratio of new and experienced members. Repeated collaboration Ratio = 1 – number of new actors / (number of new actors + consortium sum score of repeated collaboration experience). The ratio gives a weighted score for the mutual repeated collaboration experience, and ranges from 0 for consortia with only inexperienced members to 1 for consortia with only experienced members.

Level of Participation. This measure assesses whether the consortium members participated strongly or weakly in the consortium. Strong participation consists of different contributions to the consortium activities. We build partially on Mothe and Quélin (2000) who find evidence for the positive effects of both in cash and in person engagement. Next to using these indicators, we add in goods contributions to the consortium, which represent the criteria for distinct levels of engagements defined by the funding scheme studied here[15]. Organizations vary in their level of participation if they make in person, and/or in goods, and/or in cash contributions to the consortium beyond their attendance at consortium meetings.

We distinguish between organization and consortium level participation. At the *organization level* this measure is dichotomous. Individual organizations can either participate strongly (1) or weakly (0). The level of participation includes three empirical dimensions (I) in person contributions; (II) in goods contributions; (III) in cash contributions. Organizations are coded as strong participants (1) if they either provided (I) in person contributions (e.g. actively participating in the research; performing analyses; as co-promoter of the PhD student; or as co-author); or (II) in goods contributions (e.g. providing data, facilities or materials); or (III) in cash contributions. Organizations that participate weakly (0) were either not acknowledged at all in the PhD theses, additional publications and/or evaluation reports, or acknowledged for their “suggestions and discussions during the half-yearly user commission meetings”, which indicates no further involvement. At the *consortium level*, we measure the level of participation as the number of consortium members that participate strongly in the consortium (count).

In our moderated mediation analysis, the level of participation is endogenous: repeated collaboration experience influences the level of participation, which in turn increases the probability of innovation success. At both levels of analyses – organization and consortium – the level of participation has different meaning and as a consequence it is measured in different ways to make the measure congruent with the meaning of repeated collaboration experience. At the organization level, the level of participation is dichotomous. Consequently, we employ a logistic regression transformation and model ‘the probability of strong participation’ as function of repeated collaboration experience. At the consortium level, the level of participation is continuous and represents the number of strong participants. We argue that the probability of

[15] All consortia in our study are funded by a Dutch innovation funding scheme. The governmental funding program fosters R&D collaborations between university and industry. Consortium membership of both university and industry partners is a precondition, but the level of participation varies.

innovation success is highest when the number of strong participants in the consortium is moderate, rather than low or high. In order to model the probability of a moderate number of strong participants as function of repeated collaboration experience, we transform this variable in a measure of fit to the optimal value. In order to determine the optimal number of strong participants, we first test the direct effect of the number of strong participants on the probability of consortium success. It turns out that the probability of consortium success is highest when consortia have on average 2.577 strong participants. Second, we compute the measure of fit as the inverted squared deviation between the actual number of strong participants and the optimal number of strong participants, in which zero indicates a perfect fit. Finally, we model this transformed measure of fit 'participation optimum' as a function of repeated collaboration experience.

Control Variables. We use several control variables for year of the consortium start (dummies); subfield (Maritime technology, Delta technology, Water technology); consortium size (number of organizations in the consortium exclusive consortium leader); consortium duration (years since consortium start until consortium end); financial resources allocated by the funding agency (in 100,000 euro corrected for inflation with 2004 as reference year), researcher quality (Number of publications per executive researcher in 5 years since the consortium start); consortium leader experience (consortium memberships without the focal actor at the organization level; total consortium memberships at the consortium level); consortium member experience (without the consortium leader); alter experience (experience of other organizations in the consortium, only applicable at the organization level); and joint member experience (previous consortium memberships of the focal actor with the consortium partners; natural logarithm at consortium level to prevent multicollinearity). Finally, we added a two-mode network autocorrelation term (Fujimoto, Chou, & Valente, 2011; Leenders, 2002) to correct for non-independence of observations due to ties with other consortia.

4.4 RESULTS

We show the descriptive statistics and correlations in Table 1 (organization level) and Table 2 (consortium level). The analyses included 544 observations at the organization level and 96 observations at the consortium level. The number of observations in the regression analyses can vary per model due to the year and field dummies. The Variance Inflation Factors (observed maximum: 3.738) show that there is no sign of multicollinearity.

4.4.1 Organization Success

Approximately 15% of the consortium memberships (83 out of 544) achieved organization success, e.g. commercialization of the consortium results, exploitation licenses,

Table 1: Descriptive Statistics and Correlations (Organization Level)

	Variables	Mean	S.D.	1	2	3	4	5
1	Organization Success	0.153	0.360	1.000				
2	Year Consortium Start	1995	7.009	0.009	1.000			
3	Maritime technology	0.276	0.447	-0.010	-0.203***	1.000		
4	Delta technology	0.392	0.489	-0.047	0.266***	-0.495***	1.000	
5	Water technology	0.333	0.472	0.058	-0.083†	-0.436***	-0.567***	1.000
6	Consortium Size	7.199	3.988	-0.064	0.335***	-0.115**	0.264***	-0.164***
7	Consortium Duration	4.575	1.259	0.013	0.213***	-0.076†	0.184***	-0.118**
8	Allocated funding (100k)	3.631	2.203	0.050	0.371***	-0.124**	0.157***	-0.045
9	Researcher Quality	6.084	5.211	0.065	0.437***	-0.182***	0.060	0.111**
10	Consortium Leader Experience	0.636	1.010	-0.085*	0.105*	-0.112**	0.159***	-0.059
11	Consortium Member Experience	3.063	5.862	0.141**	0.279***	-0.080†	0.184***	-0.115**
12	Experience Alters	19.594	23.474	-0.009	0.578***	-0.194***	0.404***	-0.235***
13	Joint Member Experience	1.119	2.159	0.131**	0.324***	-0.164***	0.226***	-0.079†
14	Network Autocorrelation	0.091	0.147	0.089*	0.086*	0.046	0.044	-0.089*
15	Repeated Collaboration Exp.	0.182	0.568	0.125**	0.097*	-0.017	0.128**	-0.117**
16	Level of Participation	0.307	0.462	0.305***	0.224***	0.180***	0.235***	-0.056

544 observations on 96 consortia; † p < .100; * p < .050; ** p < .010; *** p < .001

Table 1: Descriptive Statistics and Correlations (Organization Level) [Continued]

	6	7	8	9	10	11	12	13	14	15
6	1.000									
7	0.326***	1.000								
8	0.469***	0.547***	1.000							
9	0.104*	0.009	0.119**	1.000						
10	0.249***	0.151***	0.163***	-0.038	1.000					
11	-0.031	0.040	0.014	0.120**	-0.092*	1.000				
12	0.644***	0.364***	0.403***	0.243***	0.383***	0.100*	1.000			
13	0.106*	0.066	0.074†	0.146***	-0.036	0.789***	0.298***	1.000		
14	-0.009	0.036	-0.006	-0.051	-0.004	0.222***	0.123**	0.205***	1.000	
15	0.086*	0.065	0.013	-0.029	0.064	0.343***	0.183***	0.304***	0.219***	1.000
16	-0.027	0.005	0.021	-0.058	0.035	-0.049	-0.047	-0.076†	0.112**	-0.024

Table 2: Descriptive Statistics and Correlations (Consortium Level)

	Variables	Mean	S.D.	1	2	3	4	5
1	Consortium Success	0.500	0.503	1.000				
2	Year Consortium Start	1994	7.105	0.053	1.000			
3	Maritime technology	0.302	0.462	-0.113	-0.218*	1.000		
4	Delta technology	0.365	0.484	0.065	0.246*	-0.498***	1.000	
5	Water technology	0.333	0.474	0.044	-0.039	-0.465***	-0.536***	1.000
6	Consortium Size	5.667	2.962	-0.042	0.326**	-0.110	0.108	-0.003
7	Consortium Duration	4.490	1.240	-0.161	0.117	-0.040	0.121	-0.084
8	Allocated funding (100k)	3.329	2.111	-0.034	0.320**	-0.060	0.047	0.010
9	Researcher Quality	5.885	5.363	0.164	0.378***	-0.214*	0.090	0.116
10	Consortium Leader Experience	0.656	0.927	0.147	0.389***	-0.124	0.095	0.024
11	Consortium Member Experience	17.354	18.393	0.006	0.662***	-0.195†	0.391***	-0.209*
12	ln Joint Consortium Member Exp.	-0.621	3.308	0.028	0.577***	-0.276**	0.265**	-0.001
13	Network Autocorrelation	0.403	0.251	0.032	0.480***	-0.002	0.257*	-0.261*
14	Repeated Collaboration Ratio	0.135	0.253	0.050	0.100	-0.050	0.213*	-0.169†
15	Level of Participation (LoP)	1.740	1.431	0.095	0.106	-0.119	0.078	0.036
16	RCR | LoP	0.146	0.319	0.048	0.103	0.006	0.068	-0.076

96 consortia; † p < .100; * p < .050; ** p < .010; *** p < .001

Table 2: Descriptive Statistics and Correlations (Consortium Level) [Continued]

	6	7	8	9	10	11	12	13	14	15
6	1.000									
7	0.134	1.000								
8	0.277**	0.441***	1.000							
9	0.072	-0.107	0.037	1.000						
10	0.031	-0.035	0.140	0.119	1.000					
11	0.418***	0.141	0.163	0.248*	0.038	1.000				
12	0.401***	0.019	0.114	0.155	0.239*	0.684***	1.000			
13	0.115	0.058	0.076	0.020	0.188†	0.316**	0.321**	1.000		
14	0.046	-0.009	-0.070	0.045	0.060	0.291**	0.121	0.121	1.000	
15	0.491***	0.150	0.082	-0.039	-0.060	0.281**	0.197†	0.110	0.060	1.000
16	0.104	-0.018	-0.027	-0.076	-0.082	0.281**	0.168	0.152	0.750***	0.140

utilization follow-up projects or PhD employment. Table 3 shows the results for the logistic regression analyses of the probability of organization success, and reports the findings pertaining to Hypotheses 1a-4a. Model 1 includes the control variables; Model 2 includes the direct effects of repeated collaboration experience of the consortium leader and the organization; Model 3 includes the direct effect of the level of participation; and Model 4 includes the interaction effects of repeated collaboration experience with the level of participation. In order to examine the potential mediating effect of the level of participation, Model 5 and 6 subsequently include the control variables and direct effects of repeated collaboration experience on the probability of strong participation. The tests for model fit, based on the chi-square test of improvement of fit in the -2 log likelihood (Long & Freese, 2006), show that all models provide a statistically significant ($p < 0.050$) improvement of fit to the data.

The direct effect of repeated collaboration experience (RCE) (Table 3 Model 2) is statistically significant ($p < 0.050$) associated with organization success and has an inverted u-shaped pattern (RCE = +1.787; RCE^2 = -0.539). Therefore, hypothesis 1a is confirmed: repeated collaboration experience has an inverted u-shaped relation with the probability of organization success. In addition, the effect of repeated collaboration experience on the level of participation (Model 6) is statistically significant ($p < 0.050$) and follows an inverted u-shaped pattern (RCE = +1.056; RCE^2 = -0.326). Therefore, hypothesis 2a is confirmed. Furthermore, the level of participation (LoP) (Model 3) has a statistically significant ($p < 0.050$) and positive effect (LoP = +1.756) on the probability of organization success and therefore hypothesis 3a is confirmed. As the direct effect of repeated collaboration experience on the probability of organization success does not become insignificant when the mediator is added to Model 3, the level of participation only partially mediates the relation between repeated collaboration and organization success. Finally, Model 4 shows that the interaction effect of repeated collaboration experience with the level of participation is statistically significant (p <

Table 3: Probability Organization Success and Active Participation

Variables	Model 1 Organization Success		Model 2 Organization Success		Model 3 Organization Success		Model 4 Organization Success		Model 5 Level of Participation		Model 6 Level of Participation	
Intercept	-2.386*	(0.949)	-1.954*	(0.971)	-2.358*	(1.024)	-2.300*	(1.034)	-2.113*	(0.920)	-1.980*	(0.929)
Consortium Size	-0.087†	(0.052)	-0.106*	(0.054)	-0.104†	(0.057)	-0.102†	(0.058)	-0.036	(0.043)	-0.041	(0.044)
Consortium Duration	0.047	(0.169)	0.025	(0.171)	0.057	(0.181)	0.074	(0.181)	0.019	(0.144)	0.011	(0.145)
Allocated funding	0.095	(0.096)	0.122	(0.098)	0.149	(0.105)	0.143	(0.105)	-0.046	(0.087)	-0.039	(0.088)
Researcher Quality	0.015	(0.031)	0.014	(0.031)	0.015	(0.033)	0.020	(0.034)	-0.009	(0.030)	-0.007	(0.030)
Consortium Leader exp.	-0.338†	(0.198)	-0.293	(0.195)	-0.221	(0.207)	-0.198	(0.213)	-0.251†	(0.144)	-0.240†	(0.145)
Consortium Member exp.	0.055	(0.034)	0.039	(0.036)	0.040	(0.038)	0.039	(0.039)	0.018	(0.031)	0.010	(0.032)
Experience Alters	0.016	(0.013)	0.008	(0.013)	0.003	(0.014)	0.001	(0.014)	0.019†	(0.011)	0.015	(0.011)
Joint Member Experience	0.024	(0.092)	0.022	(0.096)	-0.016	(0.098)	-0.012	(0.102)	0.118	(0.084)	0.123	(0.086)
Network Autocorrelation	1.237	(0.825)	0.738	(0.871)	0.261	(0.920)	-0.033	(0.972)	0.533	(0.487)	0.377	(0.495)
Repeated Collaboration Exp.			1.787**	(0.579)	1.760**	(0.654)	0.490	(0.754)			1.056*	(0.454)
RCE^2			-0.539*	(0.239)	-0.584*	(0.281)	-0.044	(0.224)			-0.326*	(0.160)
Level of Participation (LoP)					1.756***	(0.292)	1.578***	(0.322)				
RCE * LoP							3.038*	(1.172)				
RC^2 * LoP							-1.336**	(0.495)				
Intra-class correlation	0.000	(0.000)	0.000	(0.000)	0.000	(0.000)	0.000	(0.000)	0.037	(0.049)	0.038	(0.048)
Model	Logit (RE)		Logit (RE)		Logit (RE)		Logit (RE)		Logit (RE)		Logit (RE)	
Log Likelihood	-209.265		-203.574		-183.949		-180.014		-309.668		-306.578	
df	31		33		34		36		32		34	
Chi^2	44.450*		11.380**		39.250***		7.870*		46.300*		6.180*	

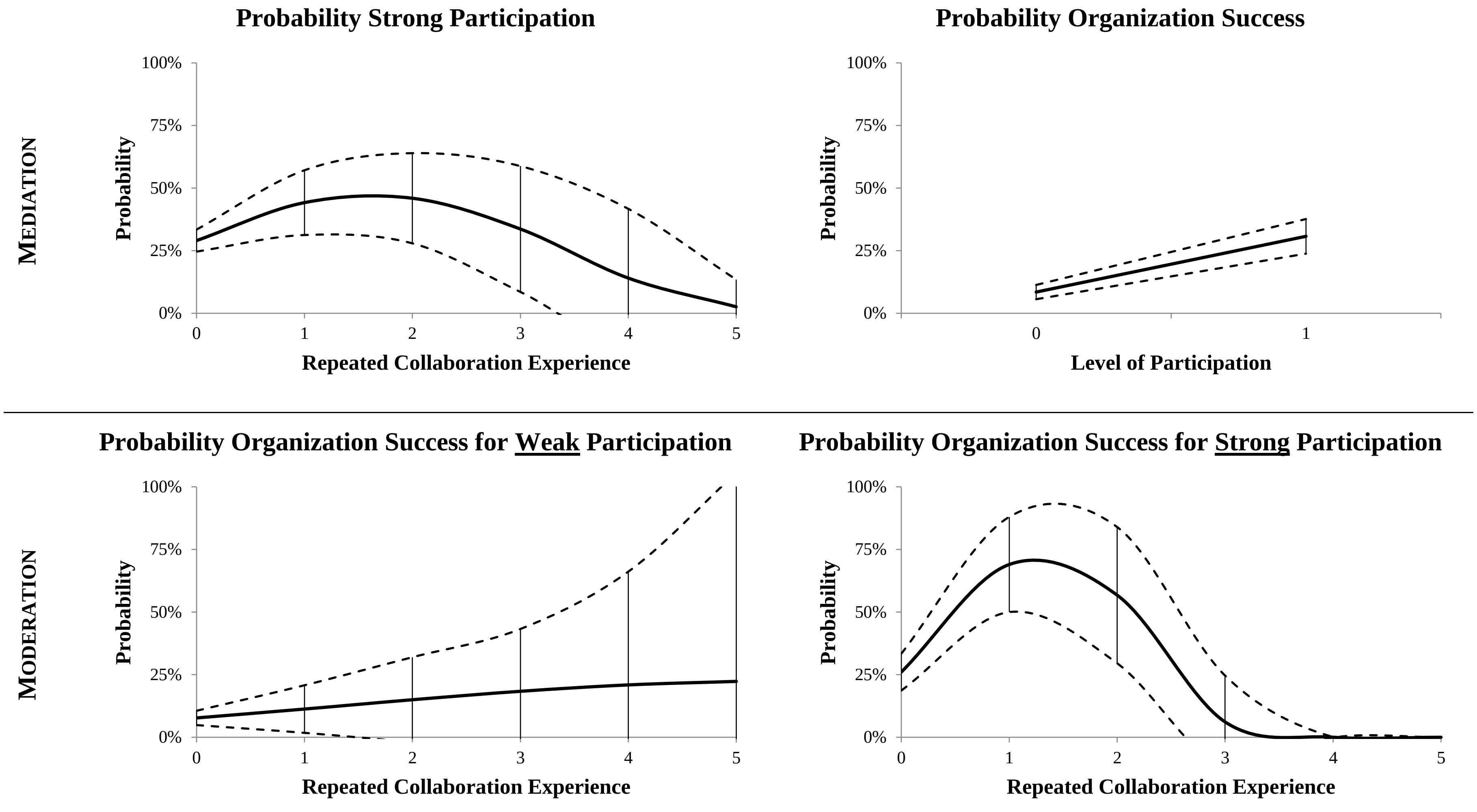
528 & 540 observations; Standard errors in parenthesis; † p < .100; * p < .050; ** p < .010; *** p < .001; controlled for observation year and subfield.

0.050) associated with organization success and has an inverted u-shaped pattern (RCE*LoP = +3.038; RCE^2*LoP = -1.336). With the inclusion of the interaction terms in the model, the direct effects of repeated collaboration become statistically insignificant. Therefore, hypothesis 4a is confirmed: The relation between repeated collaboration experience and the probability of organization success is stronger for a high level of participation relative to a low level participation. Accordingly, repeated collaboration both has a direct inverted u-shaped effect on the probability of organization success, as well as an indirect inverted-u-shaped effect through the level of participation. The remaining direct effect is completely conditional on the level of participation, as shown in Model 4. Consequently, the level of participation both functions as a moderator and as a mediator.

Figure 3 shows the average marginal effects of repeated collaboration experience on the probability of organization success, mediated and moderated by the level of participation. The top half of Figure 3 shows the mediation effect and the bottom half the moderation effect of the level of participation. New entrants (consortium members with 0 repeated collaborations) have a probability of strong participation of 29%. The first and second repeated collaboration results in an increase in the probability of strong participation to subsequently 44% and 46%. However, if organizations repeat their collaborations with the consortium leader more than twice, the probability of strong participation starts to decline and becomes statistically insignificant from 0. Accordingly, the probability that organizations participate strongly in the consortium if they already collaborated in 5 prior consortia with the same consortium leader is 26% lower than the probability that new entrants participate strongly, and even 43% lower than for organizations that have two prior collaborations with the consortium leader. Strong participants in turn have a 22% higher probability of organization success compared to weak participants.

The bottom half of Figure 3 shows the moderation effect of the level of participation on the relation between repeated collaboration experience and organization success. The probability of organization success for weak participants is close to 0%, regardless of their repeated collaboration experience. For consortium members that participate strongly, the probability of organization success has an inverted u-shaped pattern to repeated collaboration experience, and increases from 26% for inexperienced, to subsequently 69% and 57% for experience in 1 or 2 prior consortia and decreasing to 0% for repeated collaboration experience in 3 or more prior consortia. Consequently, for organizations that participate strongly and have repeated collaboration experience in 1 prior consortium, the probability of success is 69%, which is 58% higher than for weak participants with the same amount of repeated collaboration experience, and 43% higher than for strong participants without repeated collaboration experience. As the distribution of the variable repeated collaboration is skewed to the left, the evidence on the first (increasing) half of the curve is stronger, compared to the second

Figure 3: Average Marginal Effects (Organization Level)



540 and 528 observations.

(decreasing) half of the curve. Despite these differences, the post hoc tests show that both sides of the inverted u-shaped curve are statistically significant ($p < 0.050$).

4.4.2 Consortium Success

50% of the consortia (48 out of 96) achieved consortium success. Table 4 Model 1 to 4 show the results for the logistic regression analyses of the probability of consortium success. Model 1 includes the control variables; Model 2 includes the direct effects of the repeated collaboration ratio; Model 3 includes the direct effect of the level of participation; Model 4 includes the effect of the repeated collaboration ratio of strong participants (repeated collaboration ratio conditional on strong participation). Table 4 Model 5 and 6 show the ordinary least squares (OLS) regression of the participation optimum (the Inverse squared deviation between the actual and the optimal number of strong participants). Model 5 includes the control variables; Model 6 includes the direct effects of the repeated collaboration ratio. The participation optimum is derived from Model 3. Model 3, 4, 5 and 6 provide a statistically significant ($p < 0.050$) improvement of the model fit to the data.

The direct effect of the repeated collaboration ratio (RCR) on consortium success (Model 2) is not statistically significant ($p > 0.050$; RCR = -3.608; RCR^2 = +5.179), and therefore hypothesis 1b is not accepted. As the direct effect of the repeated collaboration ratio is not statistically significant associated with the probability of consortium success, the level of participation cannot mediate this relation in the strict sense (Baron & Kenny, 1986; Hayes, 2009; Preacher, et al., 2007). However, repeated collaboration experience does have an indirect effect on the probability of consortium success. The repeated collaboration ratio is statistically significant ($p < 0.050$) related to the level of participation, which in turn is significantly ($p < 0.050$) related to the probability of consortium success. The effect of the repeated collaboration ratio on the participation optimum (Model 6) is statistically significant ($p < 0.050$) and has an inverted u-shaped pattern (RCR = +11.525; RCR^2 = -12.853). Consortia with a moderate repeated collaboration ratio of approximately 45% have the best fit between the actual and optimal number of strong participants, which means that hypothesis 2b is confirmed. In addition, the level of participation (LoP) has a statistically significant ($p < 0.050$) effect on the probability of consortium success (Model 3) and follows an inverted u-shaped pattern (LoP = +2.198; LoP^2 = -0.426), which confirms hypothesis 3b. Consortia with approximately 2.577 strong participants have the highest probability of consortium success. Finally, the effect of the repeated collaboration ratio of strong participants (Model 4) is statistically significant ($p < 0.050$) related to the probability of consortium success, but has a u-shaped relation pattern (RCR | LoP = -15.826; RCR^2 | LoP = +17.006), opposite to the hypothesized effect. The probability

Table 4: Probability Consortium Success and Active Participants Optimum

Variables	Model 1 Consortium Success		Model 2 Consortium Success		Model 3 Consortium Success		Model 4 Consortium Success		Model 5 Participation Optimum		Model 6 Participation Optimum	
Intercept	-8.326	(7.080)	-6.858	(5.360)	-8.392*	(3.885)	-11.451*	(4.467)	2.552	(4.398)	3.032	(4.755)
Consortium Size	-0.050	(0.137)	-0.035	(0.124)	0.023	(0.141)	0.045	(0.153)	-0.278	(0.244)	-0.310	(0.245)
Consortium Duration	-0.621	(0.502)	-0.579	(0.436)	-0.178	(0.383)	-0.068	(0.417)	-0.637	(0.435)	-0.630	(0.448)
Allocated funding	0.191	(0.272)	0.153	(0.244)	0.100	(0.221)	-0.062	(0.238)	-0.137	(0.233)	-0.035	(0.235)
Researcher Quality	0.200	(0.159)	0.160	(0.122)	0.131†	(0.076)	0.187*	(0.091)	-0.054	(0.065)	-0.014	(0.066)
Consortium Leader exp.	1.844	(1.225)	1.612†	(0.959)	1.240†	(0.695)	1.758*	(0.812)	0.634	(0.608)	0.622	(0.615)
Consortium Member exp.	0.080	(0.061)	0.073	(0.049)	0.074†	(0.040)	0.080†	(0.041)	-0.028	(0.052)	-0.064	(0.058)
ln Joint Cons. Member Exp.	-0.242	(0.209)	-0.214	(0.179)	-0.211	(0.150)	-0.200	(0.158)	0.156	(0.179)	0.207	(0.164)
Network Autocorrelation	4.790	(3.479)	4.187	(2.719)	2.429	(1.893)	2.759	(2.169)	0.060	(0.272)	0.264	(0.293)
Repeated Collaboration Ratio			-3.608	(4.771)	-8.314†	(4.835)	-2.228	(6.340)			11.525**	(3.461)
RCR^2			5.179	(6.636)	10.124	(6.357)	2.187	(7.376)			-12.853**	(4.212)
Level of Participation (LoP)					2.198*	(0.968)	2.576*	(1.134)				
LoP ^2					-0.426*	(0.188)	-0.492*	(0.223)				
RCR | LoP							-15.826*	(7.172)				
RCR^2 | LoP							17.006*	(6.965)				
Intra-class correlation	0.337	(0.607)	0.211	(0.490)	0.000	(0.000)	0.000	(0.000)				
Model	Logit (RE)		Logit (RE)		Logit (RE)		Logit (RE)		OLS		OLS	
Log Likelihood	-50.285		-49.990		-46.124		-42.307		-220.583		-215.679	
df	30		32		34		36		30		32	
Chi^2	32.510		0.590		7.730*		7.630*		44.030*		9.810**	

92 & 96 observations; Standard errors in parenthesis; † p < .100; * p < .050; ** p < .010; *** p < .001; controlled for observation year and subfield; OLS adjusted for clustered standard errors.

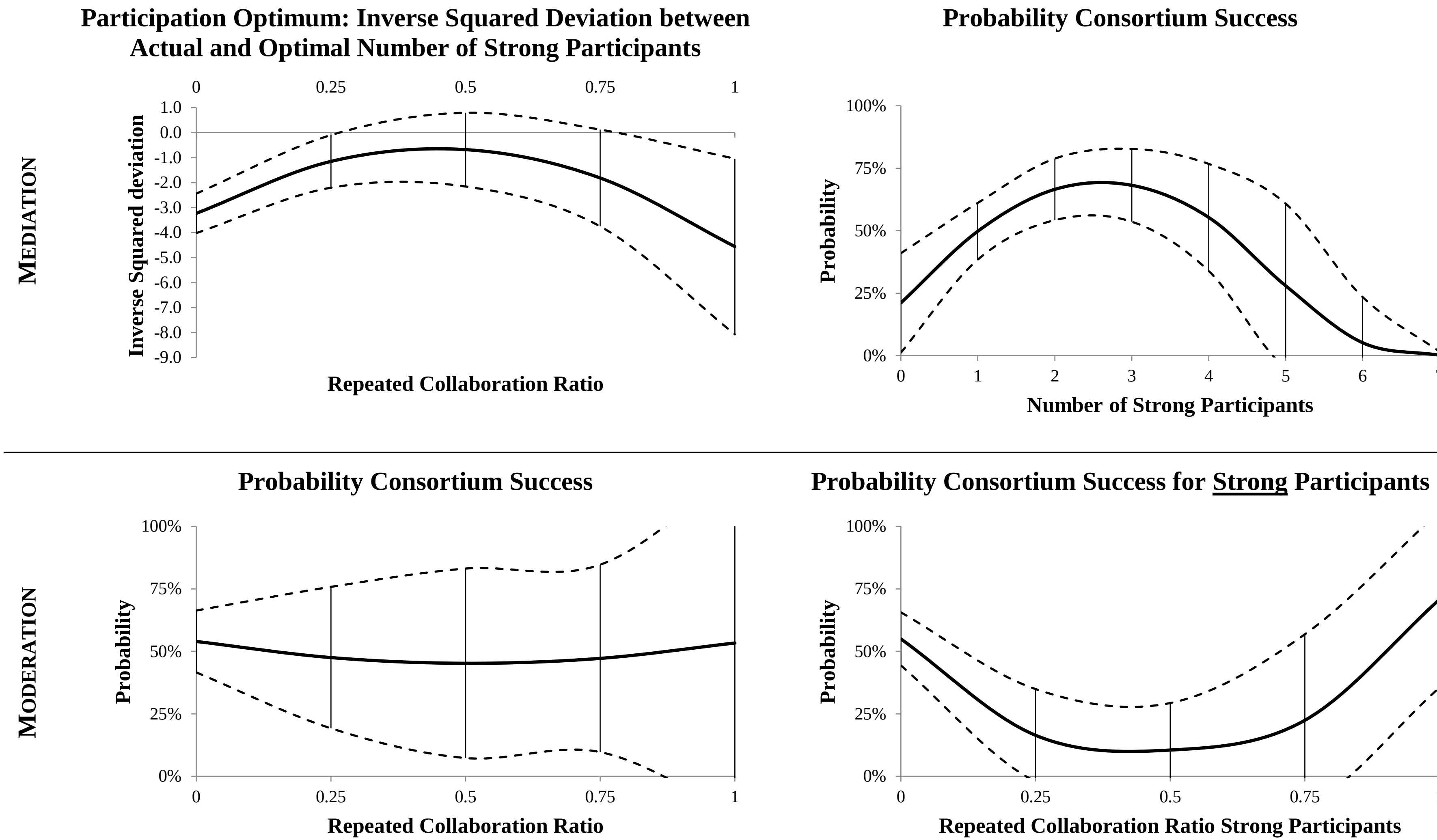
of consortium success is highest when the repeated collaboration ratio of *strong* participants is either low (all inexperienced) or high (all experienced). Accordingly, hypothesis 4b is rejected.

At the consortium level, the number of strong participants mediates the relation between the repeated collaboration ratio and the probability of consortium success, which confirms the corresponding hypotheses 2b and 3b. The moderating effect of the number of strong participants, on the other hand, contradicts hypothesis 4b. Figure 4 shows the average marginal effects of the repeated collaboration ratio and the number of strong participants on the probability of consortium success. The number of organizations that participate strongly has an inverted u-shaped relation with consortium success (northeast quadrant of Figure 4). When 2 or 3 organizations participate strongly in the consortium, the probability of consortium success is around 67%, which is about 45% higher than when no organization participates strongly and the probability of consortium success is only 21%. When 6 or 7 organizations participate strongly however, the probability of consortium success is approximately 5%, which is about 16% lower than when no organization participates strongly. Accordingly, the constraints of an excessive amount of strong participants are seemingly stronger than the constraints caused by a lack of strong participants. The optimal number of 2 to 3 strong participants is most likely when the repeated collaboration ratio of the consortium members is close to 0.5 (northwestern quadrant of Figure 4), but this ratio might simultaneously restrict the probability of consortium success if these members participate strongly (southeast quadrant of Figure 4). The repeated collaboration ratio of weak participants does not affect the probability of consortium success (southwestern quadrant of Figure 4). This leaves the consortium leader the complicated task to encourage either new participants or experienced members to participate strongly, but not both at the same time.

4.4.3 Dimensions of the Level of Participation and Success

To further unravel the contingency model, we conducted additional analyses on the different dimensions of the level of participation and organization and consortium success. Organizations can simultaneously make different strong contributions to the consortium activities and can achieve different types of success. The descriptive statistics are shown in Table 5. The most common type of strong participation results from in person contributions (19%) to the consortium. The most frequent type of organization success concerns the commercialization of the consortium results (11%), followed by the achievement of human capital (5%). Whereas most consortia achieve technological success (85%), only a minority achieves economic success (32%). Additional analyses at the organization level reveal that in person contributions have a direct effect ($p < 0.050$; In Person = +1.919) on the probability of organization success, while the effect of in goods contributions is conditional upon an

Figure 4: Average Marginal Effects (Consortium Level)



96 and 92 consortia.

intermediate repeated collaboration experience (p < 0.050; RCE*In Goods = +4.940; RCE^2*In Goods = -1.618), and in cash contributions have no statistically significant effect. The observed patterns are similar for all types of organization success.

At the consortium level, both the number of in person and in cash contributions have an inverted u-shaped relation with the probability of consortium success (p < 0.050; In Person = +9.881; In Person^2 = -1.328; In Cash = +8.655; In Cash^2 = -1.260). In goods contributions however, are not statistically significant related to the probability of consortium success. The observed results are robust for the economic dimension of consortium success, but the model does not converge for technological success. Accordingly, it can be concluded that strong participation through in person contribution is related to both organization and consortium success, while in goods contribution mainly provides (conditional) benefits for the organization, and in cash contributions can encourage the success of the consortium, but not the individual organization success.

Table 5: Level of Participation and Success

Organization level Variables	**Mean**	**SD**	**Consortium level Variables**	**Mean**	**SD**
Level of Participation	0.307	0.462	Level of Participants	1.740	1.431
In Person	0.186	0.389	In Person	1.052	1.080
In Goods	0.125	0.331	In Goods	0.708	1.004
In Cash	0.129	0.335	In Cash	0.729	1.147
Organization Success	0.153	0.360	Consortium Success	0.500	0.503
Human Capital	0.051	0.221	Technological Success	0.854	0.355
Follow-Up Project	0.028	0.164	Economic Success	0.323	0.470
Commercialization	0.107	0.309			

544 and 96 observations.

4.4.4 Robustness Tests

We conducted several analyses to test the robustness of our findings. First, we conducted multilevel regression analyses with fixed effects instead of random effects. The regression coefficients and marginal effects of repeated collaboration experience and the level of participation were comparable to the main model. The model with random effects are favored, however, because the models with fixed effects cause severe data reduction and the Hausman test was not statistically significant for most models. Second, we applied a Heterogeneous Choice Model to compare the coefficients of repeated collaboration experience across groups (strong versus weak participants) and allow the error terms (residual variance) to vary across these groups (Williams, 2009). The results are similar to the main model. Third, we used two-stage instrumental variable models to instrument the level of participation and correct for a potential bias due to correlated error terms in the two equations of the mediation model (Antonakis, Bendahan, Jacquart, & Lalive, 2010). The results correspond to the main findings. Fourth, we examined alternative operationalization of our main variables, including repeated collaboration experience expressed in years instead of number of consortia, a linear term for the repeated collaboration ratio optima and the direct effect of the optimal number of strong participants. These alternative measures confirmed our initial findings. Fifth, we investigated the relation between organization success and consortium success and showed that organization success enhances the probability of consortium success and vice versa. Nevertheless, the effects of repeated collaboration experience and the level of participation remained unchanged. Sixth, to further extend our contingency model, we explored the effects of organization success and consortium success on the probability of future repeated collaborations, but we found no indication of a potential selection bias. Finally, we included the network level predictors of chapter 5 of the dissertation to the model, but the main results remained unchanged. Summarizing, the robustness of the results is largely confirmed by alternative model specifications, operationalization and additional control variables. A summary of the results is shown in Table 6.

Table 6: Summary of the Results

Hypothesis			Observation
Direct effect			
1a. Repeated Collaboration Experience	→ ∩→	Organization success	Confirmed
1b. Repeated Collaboration Experience	→ ∩→	Consortium success	Rejected (ns)
Mediated effect			
2a. Repeated Collaboration Experience	→ ∩→	Level of Participation (O)	Confirmed
2b. Repeated Collaboration Experience	→ ∩→	Level of Participation (C)	Confirmed
3a. Level of Participation (Organization)	→ +→	Organization success	Confirmed
3b. Level of Participation (Consortium)	→ ∩→	Consortium success	Confirmed
Moderated effect			
4a. Repeated Collaboration Experience*Level of Participation	→ ∩→	Organization success	Confirmed
4b. Repeated Collaboration Experience | Level of Participation	→ ∩→	Consortium success	Rejected (U)

+ positive relation; ∩ inverted u-shaped relation; U U-shaped relation.

4.5 Discussion & Conclusion

In this study, we develop a contingency theory of repeated collaboration in multi-partner R&D consortia. In order to examine one of the central assumptions of network theory (Ahuja et al., 2012; Rawlings et al., 2015), i.e. that ties in networks are "pipes" that facilitate flows of knowledge and resources (Borgatti & Halgin, 2011; Borgatti et al., 2009; Podolny, 2001), we introduced the contingency 'level of participation'. This contingency is the extent to which individual consortium members actively mobilize their resources in order to contribute to the activities in the consortium and to signal an interest and claim a stake in innovation outcomes of the consortium. The study has addressed the question: To what extent is organization and consortium innovation success related to repeated collaboration experience, and to what extent is this relation moderated and/or mediated by the level of participation of consortium members? The study contributes to the growing literature that conducts moderated mediation analyses to open the black box of R&D collaborations (Andreeva & Kianto, 2011; Engelen & Brettel, 2012; Spanos, 2012).

Results at the organization level show that the relation between repeated collaboration experience and the probability of innovation success is both moderated and mediated by the level of participation. Organizations with moderate levels of repeated collaboration experience are more likely to participate strongly in the consortium and thereby increase their probability of innovation success (mediation), and if these organizations participate strongly, they are more likely to benefit from their resource contributions compared to organizations with low or high levels of repeated collaboration experience (moderation). These observations contribute to the very recent stream of social network research (e.g. Rawlings et al., 2015) that explores the central premise that social relations facilitate actual resource transmissions between nodes (Ahuja et al., 2012; Borgatti et al., 2009).

Our results indicate that most organizations that enter into new collaborations first employ a wait-and-see strategy (weak participation). This allows them to accumulate partner-specific information and explore advantageous partnering opportunities (Doz et al., 2000; Gulati, 1995b; Ring & Ven, 1994). Then, organizations tend to select and repeat those collaborations that both have the greatest potential for innovation success and provide them the opportunity to participate actively in the consortium (Emden et al., 2006; Mothe & Quélin, 2000; Vissa, 2011; Zheng & Yang, 2015). Organizations with moderate levels of repeated collaboration experience both are most likely to participate strongly in the consortium and have the highest probability of innovation success. By participating strongly in the consortium, organizations 'claim' a stake and voice an interest in positive outcomes, whereas organizations assuming weak participation actually abstain from such claims and opt for a role of monitoring technological developments. Investments in the R&D consortium have strong signaling value (Ozmel et al., 2013). However, not all strong participants are equally likely to benefit from their resource contributions. Particularly strong participants with moderate levels of repeated collaboration experience are likely to benefit from their contributions, while strong participants with low or high levels of repeated collaboration experience often times do not receive any tangible returns. Organizations should therefore carefully time their resource contributions, as strong participation turns out to operate only within limited bandwidths of the numbers of repeated collaborations. Organizations benefit most when they engage in repeated collaboration in one or two previous consortia, while repeated collaborations in multiple consortia rather reduce the probability of organization success, even if the organization contributes strongly to the consortium activities. Accordingly, repeated collaborations can change over time from a source of success into a liability that hampers the probability of organization success. Therefore, organizations must prevent themselves from getting locked into their web of relations (Goerzen, 2007; S. X. Li & Rowley, 2002; Sydow et al., 2009). From these findings we conclude that organizations can best enter the consortium as modest novice to accumulate information about the most beneficial mutual opportunities. Second, organizations can repeat their collaborations and mobilize their resources to achieve innovation success. Finally, after a few projects the probability of organization success decreases strongly, and organizations might decide to leave the R&D consortium.

We examined our contingency model of repeated collaboration experience not only at the organization level, but also at the consortium level. This distinction of multiple levels of analysis is motivated by the fact that a firm's incentives to participate in an R&D consortium can be twofold, namely to achieve the collective goal (e.g. new product development), and to achieve the individual goal as a consortium partner (e.g. to obtain and exploit knowledge of partners) (Cohen & Levinthal, 1989; Jones et al., 1998). Goal accomplishment – generating innovation outcomes – at both levels can be mutually reinforcing, co-existing or provide a tension between the collective and individual level. Consequently, an adequate outcome indicator for consortium membership includes both levels of analysis: the collective goal achievement and the individual goal achievement (Provan & Milward, 2001; Richard et al., 2009). Combining both levels in one study can contribute to our understanding of the functioning of R&D consortia (Lazega et al., 2008), because the explanatory mechanisms at both levels can be fundamentally different. Not the experience of an individual organization, but the composition of the consortium as a whole with regard to collaboration experience is of central importance for the consortium success (e.g. Branstetter & Sakakibara, 2002; Gomes-Casseres, 1996; Hoang & Rothaermel, 2005; Rowley et al., 2005). Therefore, we measured repeated collaboration experience and the level of participation in such a way that they express the consortium composition.

We observed no direct effect of repeated collaboration experience on the probability of consortium success. However, our results showed that consortia with moderate levels of repeated collaboration experience were more likely to optimize their level of participation, compared to consortia with very low levels of repeated collaboration experience (all inexperienced members) or very high levels (all experienced members). This implies that consortium leaders should aim at attracting both new partners, that bring non-redundant information (D. Li et al., 2008; Zheng & Yang, 2015), and experienced partners, that facilitate joint routines, mutual understanding, and collective ways of monitoring the functioning of the consortium (Das & Teng, 2002; Hoang & Rothaermel, 2005), in order to improve the functioning of the consortium. Consortia with a weighted repeated collaboration ratio of 0.5 were most likely to activate two or three organizations to participate strongly and contribute their resources. The level of participation in turn has an inverted u-shaped relation to the probability of consortium success. Consortia with too few strong participants lack organizing capacity and resources to achieve innovation outcomes, but consortia with too many strong participants can face all kinds of management issues, like goal ambiguity and rivalry amongst consortium members (e.g. Jones et al., 1998; Ring et al., 2005). Thus, organizations with moderate levels of repeated collaboration experience, are most likely to have moderate levels of participation, which in turn increases the probability of consortium success.

Our findings reveal a complicated management task for the consortium leader. It turns out that the level of participation moderates the direct effect of repeated collaboration experience on the probability of consortium success in such a way that moderate levels of repeated collaboration experience of the *strong participants* within a consortium can severely reduce the probability of consortium success. Consortia in which all strong participants are either inexperienced or experienced have much greater probabilities of consortium success, compared to consortia in which both experienced and inexperienced members participate strongly. When newcomers claim a stake in consortia where longstanding members have a strong share, the innovation process might get disturbed. Strong participation of newcomers might negate previously accumulated experience and routines of the other consortium members and can create a tension in the distribution of tasks and resources. The experience of weak participants has no influence on the probability of innovation success. This implies that consortium leaders should first attract both new and experienced members, and then encourage either the new participants or the experienced members to participate strongly, but not both at the same time.

Summarizing, our study showed that organizations with moderate levels of repeated collaboration experience are most likely to participate strongly in the consortium, and if they do, are most likely to benefit from their contributions, compared to organizations with low or high levels of repeated collaboration experience. At the same time, consortium leaders should attract both new and experienced consortium participants, but then must encourage either the new members (two or three) or the experienced members to participate strongly in the consortium. Encouraging (moderately) experienced members to participate strongly is most preferable because they can simultaneously contribute to the consortium success and achieve organization success. These observations add considerable refinement to our understanding of the functioning of R&D consortia (Doz et al., 2000; Ring et al., 2005), and the timing strategies that individual organizations and consortium leaders can employ in inter-organizational collaborations.

We started this study with the observation that previous research showed mixed or even contradictory results on the relation between repeated collaboration experience and innovation success. To enhance our understanding of this relation, we introduced a contingency theory of repeated collaboration and examined one of the central assumptions of network theory, i.e. that ties in networks are "pipes" that facilitate flows of knowledge and resources (e.g. Ahuja et al., 2012; Borgatti et al., 2009; Rawlings et al., 2015). Our contingency model demonstrates the importance of the timing of actual resource inputs for innovation success which we believe might at least partly explain the inconsistent findings in the literature so far. Organizations with too little or too much repeated collaboration experience are both restricted in their opportunities to participate strongly in the consortium, and are less likely to benefit from their resource inputs to the consortium. Thus, organizations must aim for the sweet spot of repeated collaborations in a few consortia in order to enhance their innovation success. The fact that organizations are selective in their repeats, was already demonstrated by previous research (e.g. Gulati, 1995b; Polidoro et al., 2011; Zollo et al., 2002), but this sweet spot has only been studied very recently (Zheng & Yang, 2015), and the role of resource inputs had been left virtually unexplored. The findings imply that organizations that aim to pursue long-term relations with the same consortium leader have to find ways to overcome potential creative lock-ins and inertia (e.g. S. X. Li & Rowley, 2002; Skilton & Dooley, 2010). Maintaining such long-term relations comes with a dual task. Organizations both have to search continuously for new opportunities to contribute to the consortium, and have to find new ways to claim their stake in the innovation outcome. Organizations achieve higher probabilities of innovation success if they continuously renew their partner portfolio, replacing old ties for new ties and engaging strongly in R&D partnerships of an intermediate lifespan.

Our second contribution to the network and innovation literature results from our assessment of innovation success both at the organization and the consortium level. The explanatory mechanisms at the consortium level turn out to differ fundamentally from the organization level. At the consortium level, repeated collaboration experience can also serve as selection mechanism for strongly participating organizations, but comes with two complicating issues. First, consortium leaders should not encourage too many consortium members to participate strongly, in order to avoid competition and management complexities. In case all consortium leaders want to participate strongly anyhow, it is of central importance to make clear agreements about the distribution of tasks and resources even before the consortium start. Second, a configuration of new and experienced consortium members facilitates an optimal level of participation, but consortium leaders must be selective in who they encourage to participate strongly. In case both new and experienced members want to participate strongly, mutual agreements about resource inputs, intellectual ownership, and distribution of potential innovation outcomes are key.

4.5.1 Limitations

The study has several limitations. The variables subfield, level of participation and organization success are sensitive to the coding of the researcher. Further, potential organization successes can be missing in case they are not mentioned in utilization reports, PhD-theses and publications. In addition, the number of cases at the consortium level is limited, particularly as some cases drop-out due to complete prediction of the outcome by the year and field dummies. In addition, the variables repeated collaboration experience and level of participation are skewed to the left, which makes that the evidence for the first, increasing half of the observed inverted u-shaped effects is stronger than the evidence for the second, decreasing half of the curve. Though both halves of the curve are statistically significant. Finally, the evidence on the direction of the observed effects is restricted. Even though the independent variable is based on observations before the consortium start, while the contingency reflects observations during the consortium progression, and the outcome variable reflects observations after the consortium end, little is known about the anticipation of the organizations on expected returns. Such anticipations can potentially cause a sampling bias (Berk, 1983; Hamilton & Nickerson, 2003; Heckman, 1979). Further research is needed to get more in-depth understanding of potential organizational anticipation on expected returns, as well as the role of individual representatives of the organizations in the collaboration process. We therefore call for more research that further examines the central but rarely examined assumption of network theory, that ties in a network facilitate transmissions of resources from one node to another (Ahuja et al., 2012; Borgatti et al., 2009; Rawlings et al., 2015). Such research should use a temporal lens to provide fine-grained insight in the explanatory mechanisms in social network theory.

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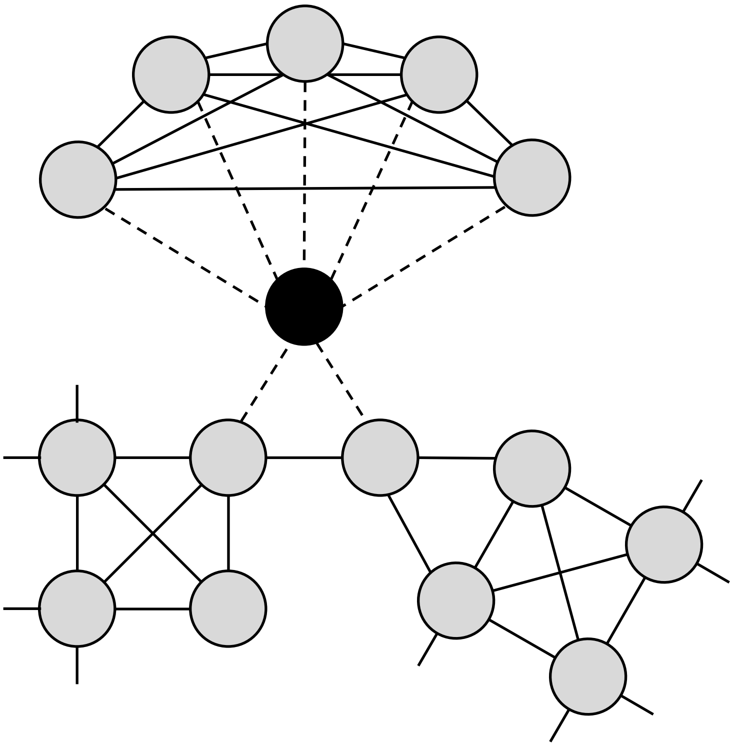
CHAPTER 5

"DON'T GRAB THAT NUCLEUS!"
HOW INNOVATION NETWORKS RISE, FALL, AND RECOVER



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ABSTRACT

Previous research on collaboration in innovation networks has demonstrated that a small-world structure facilitates innovation success. However, how dynamics at the organization level and the field network level complement small-worldliness in explaining innovation performance remains an understudied phenomenon. In this study, we synthesize small-worldliness and the stability of actor positions to provide insight in the success of innovation networks in the Dutch Water sector. We hereby pay special attention to actors that functions as central connectors. The results of our longitudinal analyses show that a structure that combines small-worldliness and stability of central connectors increases the probability of innovation success of consortia in the network. We find that the fate of the complete network is contingent on the fate of the central connectors – the ‘nuclei’ – that make up the stable core. When a nucleus is grabbed out of the network, the network most likely will disintegrate. This study advances our understanding of organization and network level dynamics in innovation networks by showing how prominence differences between organizations result in field network dynamics, which in turn influence the innovation success of the involved consortia.

Previous versions of this chapter were presented at the 3rd Amsterdam Workshop on Social Networks and Organizations (Amsterdam, 2013), and at XXXIV Sunbelt Social Networks Conference of the International Network for Social Network Analysis (St. Pete Beach, 2014).

5.1 INTRODUCTION

In this study, we explore the relation between the positional stability of structurally differentiated actors, network dynamics, and innovation outcomes. We aim to advance our understanding of the interplay between dynamics at the organization and the field network levels in innovation networks, as recently placed on the research agenda (Ahuja, Soda, & Zaheer, 2012; Amburgey, Al-Laham, Tzabbar, & Aharonson, 2008; Brass, Galaskiewicz, Greve, & Tsai, 2004).

Organizations increasingly rely on conducting R&D in networks of mutually connected inter-organizational projects in order to keep up with today's volatile markets and rapidly changing technologies (Bakker, Boroş, Kenis, & Oerlemans, 2013; Doz & Hamel, 1998; Meeus, Oerlemans, & Kenis, 2008). Previous research has demonstrated that the innovation success of the involved organizations and consortia at least partially depends on the structural characteristics of the inter-organizational network in which the organizations and consortia are embedded (Powell, Koput, & Smith-Doerr, 1996; Schilling & Phelps, 2007). Particularly networks that are characterized by a small-world structure – i.e. "high local clustering and short global separation" (Watts, 1999, p. 493) – provide fertile grounds for innovation. The global connections provide access to non-redundant information while the local clusters facilitate organizing capacity, rich information exchange, and the development of mutual trust (Burt, 2005; Lavie, Kang, & Rosenkopf, 2010; Schilling & Phelps, 2007). A few studies examined the influence of dynamics at the organization level on the development of a small-world structure at the network level (Baum, Shipilov, & Rowley, 2003; Davis, Yoo, & Baker, 2003; Gulati, Sytch, & Tatarynowicz, 2012), and conversely the influence of a small-world structure at the network level on the innovation success at the organization level (Schilling & Phelps, 2007; Uzzi & Spiro, 2005). However, we know relatively little about the dynamics within small-world structures (Ahuja et al., 2012). Especially the dynamics of global connectors has to our knowledge not been investigated to date. Moreover, we address the issue of cross-level interactions between the organization and field network level variables, which several authors have called for (Koka, Madhavan, & Prescott, 2006; Moliterno & Mahony, 2010; Raab, Lemaire, & Provan, 2013; Zaheer, Gözübüyük, & Milanov, 2010).

This study makes the following contributions to the literature on network theory. We combine arguments from small-world theory with arguments about the positional dynamics of the central connectors, and in doing so we actually revisit the core arguments of small-world theory by adding a dynamic perspective with regard to the position of global and local actors. In more detail, firstly we examine the extent to which the positional stability of individual organizations relates to the stability of the complete field network, and secondly we assess the effects of the distribution of stability and flexibility over the core and periphery of the field network in relation to the innovation performance of the involved R&D consortia.

Our central thesis is that organizations that repeatedly collaborate with the same partners in successive consortia, extend the duration of their relations, and create a stable core in their network, which in turn can increase the probability of innovation success of the involved consortia. By a stable core we mean a subset of the organizations in the complete network that is (I) well connected through multiple projects, (II) over time becomes central in the complete network, (III) remains stable by repeated collaborations over multiple projects and multiple years, and (IV) has redundant ties, despite the membership turnover. However, when such a stable core has emerged, the fate of the complete network becomes contingent on the fate of the central connectors – the 'nuclei' – that make up the stable core. To summarize when someone grabs a nucleus out of the network, the network most likely will disintegrate. Theoretically, this focus on the impact of stable core of field networks allows for a further development of established small-world arguments.

Our research question is: To what extent is the development of a stable core in the R&D network related to the stability of the central connectors in the network, and to what extent does the development of this stable core influence the innovation outcome of the consortia in the network? We explore the organization and field network dynamics of 318 consortium members of 104 R&D consortia in the Dutch water sector over 23 years. In our research context, R&D consortia are by definition time-bound, which makes repeated collaboration a premise for stable participation in the network.

In the theory section, we first introduce a taxonomy of local and global stability and flexibility in small-world structures. Second, we discuss our conceptual model on the antecedents and consequences of local and global stability. Next, we present results from analyses on (I) the field network development of the Dutch water innovation network; (II) the contextualization of the field network and its antecedents; (III) the relation between prominence of individual actors and field network stability; and (IV) the effect of local and global stability on the probability of innovation success of R&D consortia in the network. Finally, we conclude with a discussion of the findings. At present, because small world theory and theory on network dynamics provides little guidance to the development of hypotheses, we have chosen to follow an exploratory, inductive approach and hence we formulate propositions in the conclusions and discussion section.

5.2 THEORY

Theoretically, we build on small-world theory (e.g. Baum et al., 2003; Davis et al., 2003; Fleming, Charles King, & Juda, 2007; Gulati et al., 2012; Watts, 1999), and on ambidexterity theory (e.g. Adler, Goldoftas, & Levine, 1999; Tushman & O’ Reilly, 1996). Several authors have claimed that small-worldliness of the innovation network creates supportive conditions for successful innovation collaboration (e.g. Burt, 2005; Schilling & Phelps, 2007; Uzzi & Spiro, 2005). The main argument is that local clustering facilitates organizing capacity and mutual trust, while transitory shortcuts creates global connections providing access to non-redundant information (Burt, 2005; Schilling & Phelps, 2007; Watts, 1999). The issue we want to work on is how stability and flexibility of innovation networks complement the small-world explanations. Inter-organizational networks (Ahuja et al., 2012) and particularly innovation networks (Powell, White, Koput, & Owen-Smith, 2005) are fundamentally dynamic: ties dissolve when old members are replaced by new members. Examining these dynamics is particularly relevant for innovation networks, as networks relative to other organizational arrangements offer good ways to spread risks associated with uncertainties of longer term high tech R&D trajectories (Das & Teng, 2002; Lavie et al., 2010; Ring, Doz, & Olk, 2005). We build on recent studies that examined the organization level dynamics of small-world structures (e.g. Baum et al., 2003; Gulati et al., 2012), and we extend this research by examining not only the network structure per individual year, but also the stability and flexibility within this structure. In a similar fashion Soda, Usai, and Zaheer (2004), and Baum, McEvily, and Rowley (2012) examined the performance implications of tie longevity, and Sytch and Tatarynowicz (2014) tested the performance implications of general membership turnover in small-world structures.

In this study we focus on innovation networks that result from organizations participating in R&D consortia, also called two-mode networks (e.g. Borgatti & Everett, 1997; Everett & Borgatti, 2013). Networks of R&D consortia come with three particularities. First, actors form ties through multi-partner R&D consortia, which implies that a certain degree of local clustering is a given. Local clusters arise when organizations participate in a single consortium that consists of peripheral actors. Peripheral actors most likely reside in a shell of densely connected clusters (consortia) instead of sparsely connected periphery. Second, global bridges result from organizations that participate in multiple consortia and function as connectors between the different consortia, also called structural folds (Vedres & Stark, 2010). The difference between actors in a connector position versus a peripheral position is essential to the small-world structure in the network. Third, consortia are time bound by the lifespan of the underlying projects, and hence, the network structure is fundamentally dynamic, as the ties dissolve after the project has ended. Organizations that repeat their collaborations in successive R&D consortia, however, can provide some stability to the network. This also implies that network positions are not constant, instead they are temporally dynamic (Borzillo, Aznar, & Schmitt, 2011).

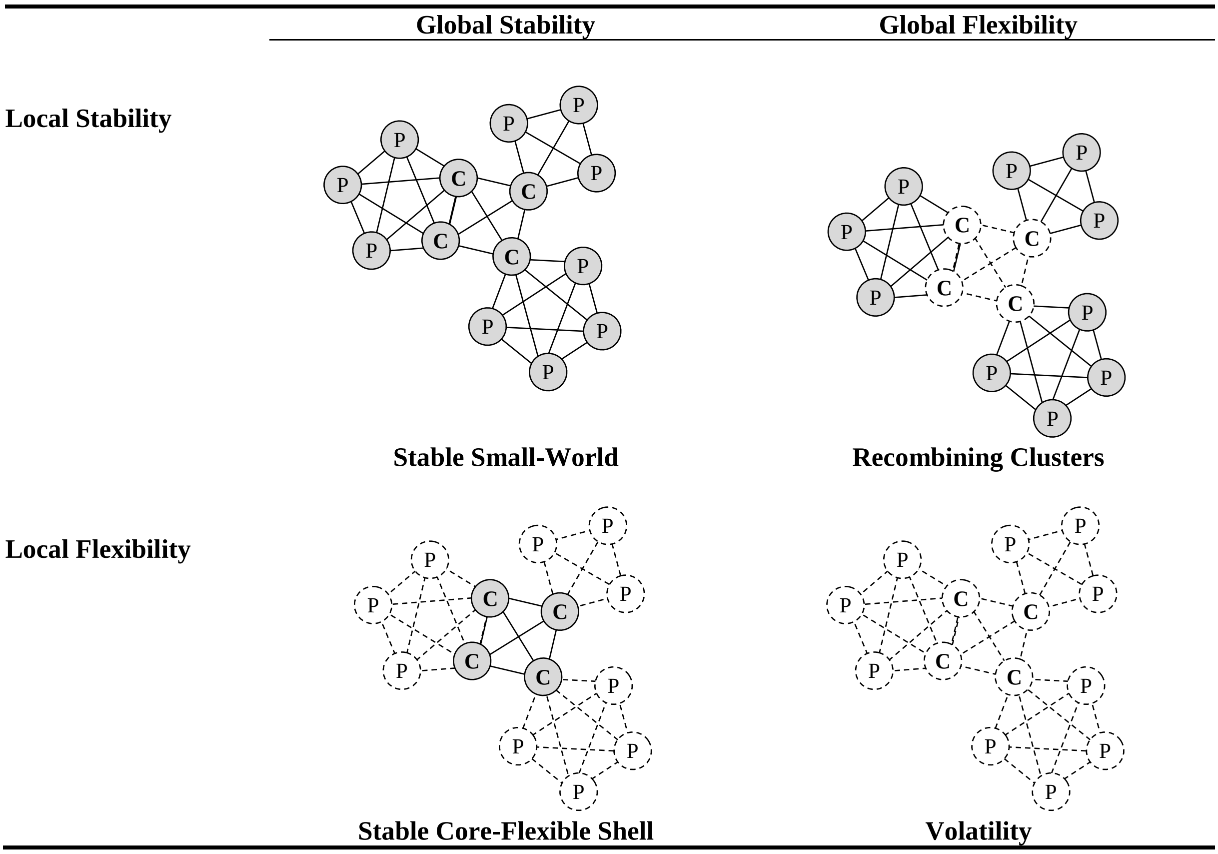
Ambidexterity theory (e.g. Adler et al., 1999; Tushman & O’ Reilly, 1996), conceptualizes collaboration in R&D consortia as a means to make firms more flexible in performing complex tasks like R&D. Consequently, it tends to ignore the fact that firms do sometimes repeat their collaborations. In contrast to the ambidexterity literature, we contend that despite the flexibility offered by R&D consortia to the focal organizations, firms do also actively contribute to network stability through repeated collaboration in multiple R&D consortia over time. This search for stability in flexible, time-bound organizational arrangements has major consequences for the development of the network structure and evolution. Organizations that repeatedly collaborate with the same partners in successive consortia and extend the duration of their relations actually create a stable core in the network. This stable core enhances the retention of joint knowledge and the attraction of new resources and participants, while a shell of new participants surrounding the core safeguards the flexibility of network collaboration. A stable core-flexible shell structure arise in the network when the central connectors in the network repeat their collaborations and extend their participation, while new entrants replace the peripheral actors in local clusters. Particularly when time-bound inter-organizational projects shape networks, the repeated collaboration of these central connectors provide a stable core to the network, which is of vital importance for the functioning and connectedness of the complete network.

In Figure 1 we present a taxonomy (Figure 1) that combines small-worldliness under conditions of local and global stability and flexibility for local and global actors. With respect to the small-worldliness of the network, Gulati et al. (2012) argue that:

> “Two key actor-level processes are likely to explain the emergence of a small world in this context: (1) the formation of local ties that connect pairs of contacts located within the same network community and thus create dense clusters of tightly interconnected actors, and (2) the forging of bridging ties between actors from different clusters, which bind these clusters together into what becomes the small world” (Gulati et al., 2012, p. 451).

Figure 1 is a summary of our stable core theory, and adds to the processes described by Gulati et al. (2012) about the formation of small-worlds, a dynamic view, by showing how the stability of the network positions of local and global actors vary over time. We consider actors local or peripheral when they participate in only one consortium at a time, and therefore end up in the periphery of the innovation network. Global actors participate in multiple consortia and thereby build bridges between local clusters, which we also call ‘connectors’. Both local and global actors can vary in their positional stability (local/global stability vs. local/global flexibility). Local stability refers to the ongoing participation of peripheral actors in local clusters. Global stability refers to the extent to which the actors that connect the different clusters participate continuously in their connector role. In case both the connectors and the peripheral actors have been in the network for an extended period of time (local and global stability), the network is defined as a stable small-world. In the other three cells there is always relatively higher turnover either in global actors, or in local actors, or in both, which alters the nature of the small-worldliness. Networks with stable actors in the periphery (local stability) and relatively new connectors (global flexibility) are characterized by recombining clusters, i.e. stable clusters with new cross-links. Networks with stable connectors (global stability) and new peripheral actors (local flexibility) have a stable core-flexible shell structure. Finally, networks with both new connectors (global flexibility) and new peripheral actors (local flexibility) have a high volatility.

Figure 1: Local and Global Stability and Flexibility in Small-World Structures



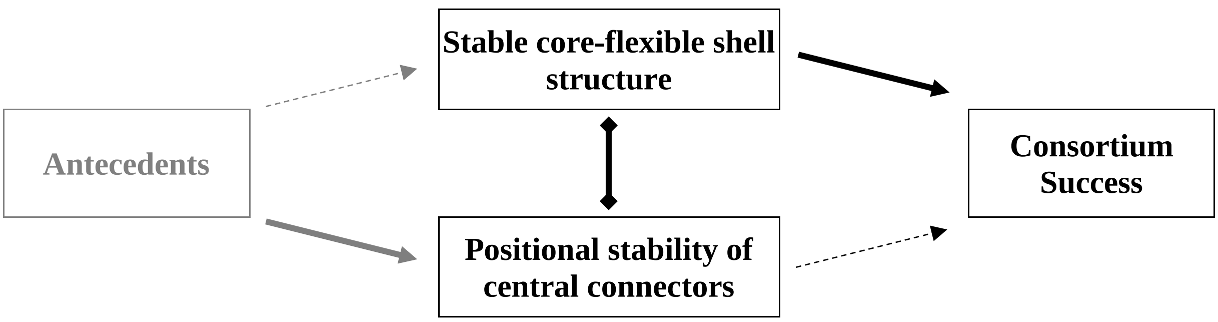
C=connector; P=peripheral actor; gray=stable; dashed=flexible.

5.3 TOWARDS A RESEARCH MODEL

Our conceptual model (Figure 2) is rooted in the work of Ahuja et al. (2012), who argue that field network dynamics are an aggregate of organization level dynamics in the innovation network. In other words, organizational action adds up to network dynamics to the extent that subsets of actors shape ties, or to the extent that they dissolve ties (Amburgey et al., 2008).

These actor-level processes of small-worldliness are not exogenous, but are influenced by e.g. the willingness and ability of individual organizations to form local ties (Ahuja et al., 2012), or by industry events that can disrupt the formation of bridging ties (e.g. Madhavan, Koka, & Prescott, 1998; Schilling, 2015). For a comprehensive discussion on the antecedents of small-world structures we refer to the studies of Baum et al. (2003), Davis et al. (2003), Rosenkopf and Padula (2008), and Gulati et al. (2012). In contrast to the aforementioned literature, we do not examine the initial development of a small-world structure. We rather focus on the distribution of stability and flexibility across this structure at the field network level, which depends on particular organization level dynamics, namely the positional stability of central connectors and peripheral actors. These organization level dynamics – positional stabilities of actors – boil down to the number of years that actors participated in the field network by means of their membership of R&D consortia, i.e. their repeated collaboration in multiple consortia over multiple years. Although we analyzed the antecedents of the positional stability of actors[16], we focus on the relation between the positional stability of individual actors and the local and global stability in the complete field network, and the subsequent innovation outcomes on the consortium level.

Figure 2: Conceptual Model



Solid arrow = direct effect; dashed arrow = indirect effect; antecedents tested in additional analyses (Appendix B)

5.3.1 The Relation between Prominence of Individual Actors and Field Network Stability

Previous research on organization and field network dynamics of small-world structures (e.g. Baum et al., 2003; Gulati et al., 2012), assumed that the role of individual actors to form

[16] In appendix B we summarize the findings of the analyses of the antecedents for the positional stability of organizations.

local or bridging ties at the organization level adds up to dynamics at the field network level, without accounting for differences between actors. We therefore challenge this assumption and argue that not every actor has the same impact on these field network dynamics. We introduce the term 'prominence' for the extent that organization level dynamics – positional stability of individual organizations – results in dynamics of the complete field network in terms of local and global stability of the small-world structure. We do not assume that these organization level dynamics merely result from organizational agency, because other conditions such as exogenous events or structural constraints might also influence these dynamics. Our thesis is that the prominence of individual actors in the dynamics of the complete field network is heterogeneous, as some actors are more prominent than others.

Two important indicators for prominence are the current position – e.g. connectors versus peripheral actors – and the past positional stability of an actor. First, the impact of organizational actions on the field network dynamics is contingent on the network positions of an actor. While actors with a peripheral position have little impact on the cohesiveness of a network, and merely affect the size of the field network, actors in the core of the field network can have a strong influence on the connectedness and stability of the complete field network. When prominent actors exit the network, the network can collapse in unconnected components, whereas the exit of peripheral actors will have no impact on the number of components of a network. Second, also the positional stability can be decisive for the prominence of an actor in the dynamics of the complete field network. Previous research on network dynamics and small-world structures either studied the network structure year-by-year (e.g. Gulati et al., 2012) or examined the stability of ties (e.g. Baum et al., 2012; Soda et al., 2004). In networks of R&D consortia, however, global bridges are not formed through individual ties, but through overlapping members that collaborate in multiple time-bound consortia. Central connectors have to repeat their collaborations in order to maintain both their position and the wider network structure. Two organizations may have the same position in the field network, yet differ in their prominence, because one organization has just taken a connector position while the other one fulfills this position already for many years. Over time, central connectors accumulate insight in the knowledge and resource dispersion across the field network (Borgatti & Cross, 2003), provide stability to the field network, and attract new entrants who bring non-redundant information to the field network (Uzzi, 1997). Therefore, we expect that the prominence of stable connectors in the dynamics of the field network is larger than the prominence of new connectors or stable actors in peripheral positions. Hence, our defenition of prominence adds a dynamic understanding of the importance of actors in networks to the original defenition by Knoke and Yang (2008).

5.3.2 The Influence of Field Network Dynamics on the Innovation Success of R&D Consortia

One central incentive for R&D partnering is to get timely access to diverse resources and skills that are widely dispersed over increasingly specialized companies (e.g. Powell et al., 1996; Schilling & Phelps, 2007). Organizations can form R&D consortia to get access to these resources, to align joint activities, and to share the risks that are associated with innovation trajectories (Das & Teng, 2002; Oerlemans & Meeus, 2009). Joint membership in multiple R&D consortia results in the development of a wider innovation network. We argue that such an innovation network can be considered as succesful in case the consortia that shape the network achieve innovation outcomes that are technologically and economically viable. The extent that consortia achieve innovation success will at least partially depend on the structure and dynamics of the field network, which the R&D consortium is embedded in. Previous research has demonstrated that a small-world structure enables exploration and creativity (Sullivan, Tang, & Marquis, 2014; Uzzi & Spiro, 2005), and is particularly suitable for innovation networks (e.g. Burt, 2005; Gulati et al., 2012; Schilling & Phelps, 2007). The main argument that explains the efficacy of small-world structure is that such a network combines local clusters with global bridges, i.e. ties that sparsely connect the local clusters. The local clusters can provide trust and rich information exchange (Coleman, 1988), while the global bridges provide access to non-redundant information (Burt, 2005).

Our main goal has been to refine the small-world argument by means of a temporal perspective that captures the ways in which stability and flexibility are balanced across the field network. This reasoning has been summarized in Figure 1 that offers a typology that describes four combinations of global and local stability and flexibility. Balancing of global and local stability and flexibility can be pursued over time and space by an alternation of local and global reaching out to distinct partners, i.e. optimal matching of local and global partnering. We argue that the probability of innovation success is the greatest if stability and flexibility is spread out across the local and global part of the network in two specific ways (Lavie et al., 2010; Schreyögg & Sydow, 2010), i.e. if either the local or the global stability is high, while the other is low. So we expect that a field network with a ‘Stable core-flexible shell’ structure respectively a ‘Recombining clusters’ structure, in which local clusters are stable and the global connectors are flexible, will on average perform better than stable small-worlds and completely volatile structures. This is because consortia in such networks have both access to non-redundant information from new partners and maintain established relations through which they develop trust, organizing capacity, and knowledge sharing practices for rich information exchange (Lavie et al., 2010; Sytch & Tatarynowicz, 2014). Particularly the stable core-flexible shell structure can increase the probability of innovation success, because these networks both develop ways to preserve past R&D experience (Borgatti & Cross, 2003) and provide access to diverse and non-redundant resources (Sytch & Tatarynowicz, 2014; Uzzi, 1997).

5.4 METHODS

5.4.1 Sample

The sample consists of 318 organizations that participate in 104 R&D consortia in the Dutch Water sector, which includes the subfields Maritime technology, Delta technology, and Water technology. These organizations form the field network through overlapping membership ties in these R&D consortia. We chose the Water sector since it is one of the most innovative economic sectors in the Netherlands (Karstens et al., 2011; Maritiem Cluster in de Topsector Water, 2011), which is characterized by a combination of stable actors and new entrants that collaborate in temporary R&D consortia (Levering, Ligthart, Noorderhaven, & Oerlemans, 2013). This characteristic of the field network makes it possible to observe both the network dynamics and the related innovation outcomes. We acquired the secondary data from annual reports published by a Dutch funding agency that implements a Dutch university-industry collaboration policy. Between 1982 and 2004 the agency funded 104 R&D consortia in the Water sector. These R&D consortia consist of a consortium leader, connected to one of the Dutch Universities, and a user committee of organizations, like Deltares, Shell, the Royal Navy or Witteveen+Bos. The funding agency publishes evaluations of all consortia at 5 years and/or 10 years after the consortium start. These evaluation reports include information on the consortium leader and members, consortium start year, end year, allocated funding and consortium success. Due to missing data, the analyses on consortium success include 97 consortia. The average consortium duration was 4.42 years. Consortia included one consortium leader and on average 5.45 members. In addition to the secondary data, we acquired primary data in 51 interviews based on a stratified sample of respondents (based on the actor type, repeated collaboration, field and performance). Some respondents (26 out of 51) have participated in multiple consortia, and we interviewed them about all the consortia they participated in. The respondents represent in total 80 different consortia in the Water sector. For this study, we used material from the interviews that zooms in on developments and events in the Dutch Water sector that the interviewees considered to be of central importance for the inter-organizational collaboration.

5.4.2 Measures

Consortium Success. The value for consortium success is derived from the evaluation reports of the agency that funds the R&D consortia in our research population. This agency has appointed an external committee of specialists to rate the innovation results of the funded consortia. In this study we use three criteria of these external evaluations[17], namely the (I) member involvement; (II) product development, and (III) income achievement by the R&D consortium. The innovation success of an individual consortium is coded as high (1) if the average score on the three criteria is at least sufficient (2 on a scale from 0 to 3), and the consortium innovation success is coded as low (0) if the average score was below 2. We applied separate analyses on the individual criteria.

Network Data. We track the evolution of the innovation network in the Water sector between 1982 and 2004. Nodes in the network are consortium leaders (university representatives) and consortium members (representatives of firms from service and manufacturing). We count inter-organizational relations, if and only if a joint consortium membership occurs in a given year. The strength of relations derives from joint participation of organizations in multiple consortia.

Theoretically we distinguished between several types of actors, and this distinction is based on past network positions. Our main distinction in past network position pertains to peripheral actors in local clusters and connectors that link these clusters. This implies that connectors are on the shortest path between any pair of other actors, the betweenness centrality of connectors is larger than zero, and for peripheral actors it is zero. In line with previous research, we examined the connectedness to the largest component and small-worldliness of the field network (e.g. Fleming et al., 2007; Gulati et al., 2012), and we added the global and local stability. The complete network per year is the unit of analysis.

Largest Component. We used UCINET (Borgatti, Everett, & Freeman, 2002) to determine the number of components in the network and computed the percentage of actors connected the largest component.

Small-Worldliness. We measured the small-worldliness of the network as ratio between the clustering coefficient and average path length, both expressed in relation to a random network, as frequently used in prior research (e.g. Baum et al., 2003; Gulati et al., 2012; Watts, 1999).

Global Stability. Global stability is the average percentage of prior years in which current connectors (linked to the largest component) have participated in the network. For connectors that became disconnected from the largest component, we used the inverted value, in the sense that stability of connectors linked to the largest component increase the global stability and connectors isolated from the largest component decrease the global stability[18].

[17] These three criteria cover the objectives of the Technology Program for university-industry collaboration.
[18] E.g. in case of a network with four connectors, of which three are connected to the largest component and participated in the network for the full observation period, while the fourth is disconnected from the largest component and participated half of the observation period, the average global stability = (3*100% - 1*50%)/4 = 62.5%.

Local Stability. Local stability is the average percentage of prior years in which current peripheral actors have participated in the network.

Prominence. We measure the prominence of an individual actor as the change in local or global stability of the complete network, when the individual actor is (hypothetically) excluded from the network.

Disruption. Disruption is an operationalization of ‘industry events’, one of the antecedents of network dynamics according to Ahuja et al. (2012). In our research setting disruption equates to the major network disruption in 1992, which we discuss in detail in our qualitative assessment of the interview results.

Control Variables. In our analysis of consortium success, we use the control variables subfield (Maritime technology, Delta technology, Water technology); consortium size (number of consortium members); consortium duration (years since consortium start until consortium end); allocated funding (in 100,000 euro corrected for inflation with 2004 as reference year), researcher quality (expressed as the number of publications per executive researcher in 5 years since the consortium start), and a two-mode network autocorrelation term (Fujimoto, Chou, & Valente, 2011; Leenders, 2002) to correct for non-independence of observations that results from relations between consortia.

5.4.3 Analyses

Our analyses follow the conceptual model of Figure 2. First, we provide a general description of the field network development of the Dutch water innovation network. Second, based on the interview results we substantiate and contextualize an actor perspective on the function and role of the field network for their R&D tasks and its antecedents. Third, we test the relation between prominence of individual actors and field network stability. Fourth, we examine the effect of local and global stability on the probability of innovation success of R&D consortia in the network.

Descriptive Statistics of Field Network Dynamics. We make a qualitative assessment of the development of the water innovation network. In addition, we determine the different periods in the network development by means of a k-means partition cluster analysis of the percentage of actors connected to the largest component. Connectedness to the largest component is a central premise in small-world studies, as small-worldliness can only be defined if the involved actors are connected by any path (e.g. Davis et al., 2003; Fleming et al., 2007; Gulati et al., 2012; Uzzi & Spiro, 2005), while at the same time a stable core in the network is likely to attract all actors to the largest component due to preferential attachment mechanisms (Barabási et al., 2002; Powell et al., 2005). We conducted several robustness tests (Appendix A) to examine the validity of our periodization.

Contextualization of the Field Network: Interview Results. We recorded, transcribed, and coded all interview material in an iterative process in which we worked back and forth between the emerging framework and the transcripts to substantiate and contextualize organization and field network dynamics, and its antecedents. For validation purposes we also applied a combination of logistic and OLS regression analysis to test the extent into which the organization level dynamics can be attributed to some of the antecedents distinguished by Ahuja et al. (2012), Madhavan et al. (1998) and Schilling (2015) (Appendix B) .

The Relation between Prominence of Individual Actors and Field Network Stability. To examine the prominence of individual actors in the dynamics at the field network level, we conducted the following test. Per observation year, we hypothetically removed each network member case-by-case and computed the difference in local and global stability of the complete network before and after removing an individual member. Subsequently, we calculated the average ‘prominence’ of an individual actor in the local and global stability of the network over all observation years. In addition, we computed per observation year the maximum change in network stability due to the exclusion of a single actor. Finally, we made a qualitative assessment of the dynamics of the most prominent actors in the network.

The Influence of Local and Global Stability on the Innovation Success of R&D Consortia. In order to test the relation between dynamics at the field network level in terms of local and global stability and the probability of innovation success of consortia in the network, we applied a logistic regression analyses with network level random effects. In addition, - for non-linear models this procedure is particularly recommended - we compute the average marginal effects of local and global stability and provide a graphical representation of the interaction effect (Hoetker, 2007; Karaca-Mandic, Norton, & Dowd, 2012). We conducted logit and marginal effects analyses for the separate dimensions of consortium success, i.e. member involvement; product development, and income achievement by the R&D consortium.

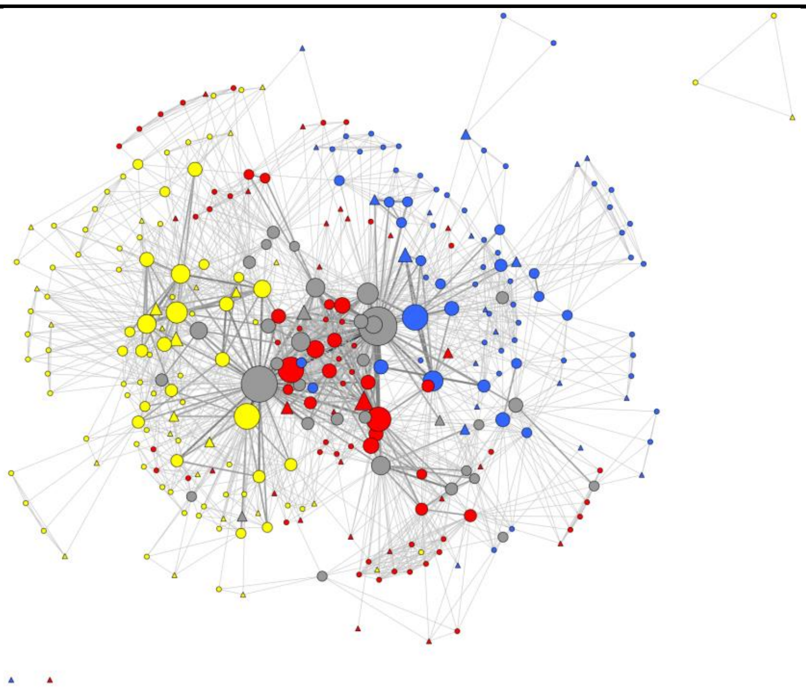
5.5 RESULTS

In this section, we first describe the field network dynamics of the Dutch water innovation network. We provide several additional analyses on our periodization in Appendix A. Second, we provide a substantiation and contextualization of the field network dynamics based on our interview results. In addition, to validate some specific issues in the dynamics of the field network we explore whether the theoretically defined antecedents by Ahuja et al. (2012) for field level dynamics do indeed apply in this specific case (Appendix B). Third, we show how field network dynamics relate to the prominence and stability of prominence of individual actors. Finally, we examine the influence of field network dynamics, particularly global and local stability, on the probability of innovation success of R&D consortia in the network.

5.5.1 Descriptive Statistics of Field Network Dynamics

The field network in Figure 3 aggregates data that cover a period of 23 years in one graph. We infer from Figure 3 the presence of a stable core of repeatedly collaborating actors, and a flexible shell of actors that participate only in one or two consortia. The node size reflects the participation frequency of actors, the tie strength indicates the number of joint memberships in consortia between two actors. Figure 3 reveals that most actors are mainly active in a single subfield, either in Maritime technology (concentrated at the right-hand-side), or in Delta technology (in the middle of the network), or in Water technology (concentrated at the left-hand-side of the network). Two actors have a particularly central position in connecting the subfields: RWS Waterdienst (RIZA)[19] is the large gray actor at the middle left and connects the subfields Water technology and Delta technology. Deltares (WL | Delft Hydraulics)[20] is the

Figure 3: Aggregated Network Water Sector 1982-2004



Triangle:		Consortium leader.	Blue:		Maritime technology.
Circle:		Consortium member.	Red:		Delta technology.
Line:		Joint Consortium.	Yellow:		Water technology.
Node size:		Participation frequency.	Gray:		Mixed
Line size:		Joint consortium frequency.			

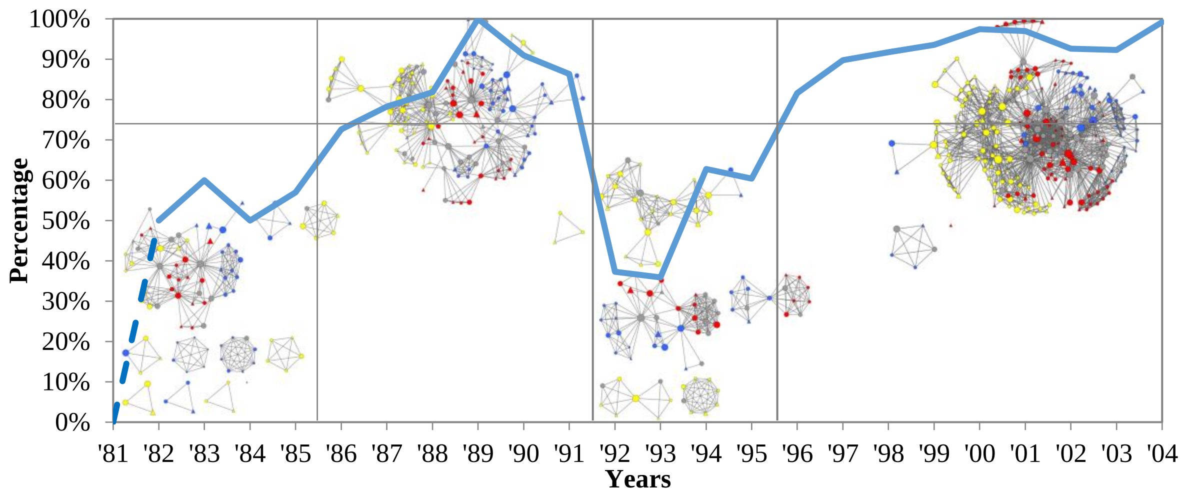
23 network years; 318 network members; 104 consortia.

[19] Formerly RIZA, nowadays integrated in Rijkswaterstaat Waterdienst.
[20] Formerly WL | Delft Hydraulics, nowadays integrated in Deltares.

large gray actor at the middle right and connects the subfields Delta technology Delta technology and Maritime technology.

To develop some intuition for the development of the network, we examine the percentage of actors connected to the largest component, a central premise for small-worldliness of the network (e.g. Davis et al., 2003; Fleming et al., 2007; Gulati et al., 2012; Uzzi & Spiro, 2005). It turns out that the percentage of actors connected to the largest component is particularly high in years that a stable core (high global stability) characterizes the network. Figure 4 shows the percentage of actors connected to the largest component in the network, indicating two periods of relatively low connectedness with on average 50% of the actors connected to the largest component (1982-1985 and 1992-1996), and two periods of relatively high connectedness with 75%-100% of the actors connected to the largest component (1986-1991 and 1996-2004). From 1986 onwards, the network develops into a stable core-flexible shell structure, until the year 1992 when the network falls apart. After this brief period of disruption, the stable core-flexible shell structure in the network seems to recover. A k-means partition cluster analysis confirms our descriptive inferences, as the percentage of actors connected to the largest component indeed cluster in two periods of low connectedness (1982-1985 and 1992-1996), and two periods of high connectedness (1986-1991 and 1996-2004)[21].

Figure 4: Actors Connected to the Largest Component in the Network



23 network years. We plot the observation period from 1981 to 2004, because the Technology Program for university-industry collaboration started in 1981. Do note, however, that the first consortia in the Water sector started only in 1982.

[21] The robustness of our periodization is confirmed by means of several robustness tests (Appendix A).

5.5.2 Contextualization of the Field Network of the Dutch Water Sector: Interview Data.

In order to get insights in the antecedents of these network developments, we conducted 51 interviews with consortium leaders and members. We asked these respondents about the most important developments in the Water sector during the observation period, and their implications for the collaboration between organizations. 80% of the respondents mentioned or referred to one or more antecedent(s) for network change. The coding process resulted in four central antecedents for network change.

First, almost half of the respondents (45%) referred to the influence of societal and economic developments on collaboration in the innovation network. Respondents argued that the network changed over time, because of a general increase in collaboration (e.g. due to increased inter-dependency, but also as general societal development), diminishing resources, and increased competition. Respondents described the temporal dynamics in these antecedents as gradual temporal processes that mainly cause a smooth intensification of the collaboration.

Secondly, many respondents (41%) mention institutional changes as important antecedents for network change. They refer to changes in policies and legislation (at the national or European level) and potential changes in funding schemes. Most respondents describe these changes as a punctuated temporal process, e.g. the sudden introduction of a new rule that caused an immediate demand for collaboration. Sometimes, these changes are a direct effect of environmental shocks. One interviewee stated for instance: “In 1993 and 1995 we had the floods on the rivers. And the [subsequent] Delta Act[22] for the rivers gave a boost to a lot of research”.

Thirdly, many respondents (39%) argue that organizational changes influence collaboration in the innovation network. They mention for instance the founding of a new organization (e.g. a research institute) and the reorganization of an existing organization. One interviewee argued for instance: “It [the increased collaboration] was caused by the internal reorganization of RWS Waterdienst (RIZA). Before that time [1995], RIZA did not work in my field of expertise, so I had nothing to do with them. But then they have expanded their work domain […] Due to their task expansion RIZA entered my field of expertise.” It turns out that organizational changes are often described in terms of sudden, punctuated changes.

Finally, some respondents (6%) refer to environmental shocks as antecedent of network change. Interviewees described particularly floods as important environmental shocks, given that approximately half of the Netherlands is located below sea level. The most severe flood occurred in 1953 and had long-term implications for R&D in the Water sector in the Netherlands, which has been the major reason for which The Netherlands has such an elaborate

[22] The Delta Act is the statutory basis for the Dutch Delta Program, including a Delta Fund for flood protection and fresh water supply, and Delta Commissioner responsible for the implementation of the program.

R&D infrastructure, a vital water engineering sector, and associated industry sectors. One of the interviewees stated: "In 1953, something happens [The North Sea flood] which gives them [Deltares (WL | Delft Hydraulics)] a lot of work for years. No wonder that this organization becomes important to the country."

What stands out is that interviewees emphasize antecedents for network change that they do not control. Many interview respondents referred to the central roles of Deltares (WL | Delft Hydraulics) and RWS Waterdienst (RIZA) in the development of the network. Both internal reorganizations in these organizations and institutional changes that affected these two organizations seemingly have important implications for the network development. Furthermore, the interview results suggest that several sudden changes in the network concentrate around the year 1992. In this year, a major disruption of the network occurred. We present an overview of the interview results in Table 1.

Table 1: Antecedents for Network Change – Interview Results

Antecedent	Prominence
Societal & Economic Development	45%
Increased Collaboration	29%
Diminished Resources	18%
Increased Competition	4%
(Temporal process: 96% Gradual; 4% Punctuated)	
Institutional change	41%
Policies and legislation	24%
Funding scheme	22%
(Temporal process: 19% Gradual; 81% Punctuated)	
Organizational change	39%
Founding	12%
Reorganization	35%
(Temporal process: 5% Gradual; 95% Punctuated)	
Environmental Shock	6%
Flood	6%
(Temporal process: 0% Gradual; 100% Punctuated)	
Any antecedent mentioned	80%

51 interviews with 13 consortium leaders and 38 consortium members.

For validation purposes we applied a combination of logistic and OLS regression analyses to explore the extent to which the positional stability of individual actors can be attributed to some of the antecedents distinguished by Ahuja et al. (2012), Madhavan et al. (1998) and Schilling (2015).[23] It turns out (Table B2 Appendix B) that the disruption variable,

[23] As the chapter would be too crowded with theoretical arguments and results we have chosen to put the analyses based on Ahuja et al.'s (2012) antecedents in Appendix B.

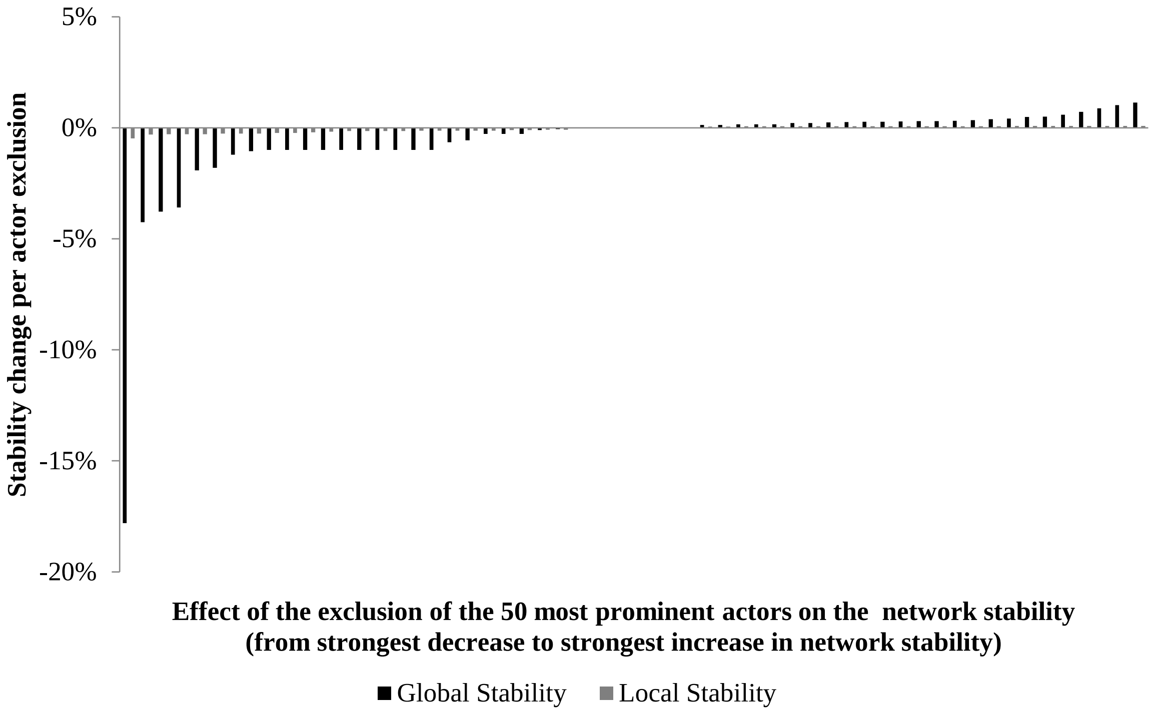
that pulls together the co-occurrence of institutional changes, organizational changes and environmental shocks had the most significant effect on the connectedness of actors to the largest component, their small-worldliness and specifically global stability. Our research question focuses strongly on stability-flexibility of field networks on the one hand, and on the other hand the small-worldliness of networks. So far, we mainly described the findings pertaining to the dynamics at the level of the field network. In the following, we discuss the relation between prominence of individual actors and the field network stability.

5.5.3 The Relation between Prominence of Individual Actors and Field Network Stability

In the previous section, we discussed general antecedents that influence the positional stability of individual actors in the network. According to Ahuja et al. (2012) organization level dynamics – in our study the positional stability of actors – add up to dynamics of the complete field network. Only in a few occasions researchers raised the issue of node heterogeneity especially in terms of behavior and preferences (e.g. Zaheer et al., 2010), but to our knowledge we are the first to explore how actors are heterogeneous as to their impact – we called this ‘prominence’ – on the dynamics at the level of the field networks. To examine prominence we advance a new measure. We assess prominence of actors at both local and global network level by removing the individual actor from the network. We assess the prominence of single actors with a calculation of the average changes in local and global stability over a period of 23 years when removing these actors from the node set. Figure 5 shows the prominence distribution for each of the 50 most prominent (positive and negative) actors in the network. The prominence distribution of global stability seems rather skewed: a few actors have a very high prominence score and all other actors have a very low prominence score. For local stability on the other hand, the prominence distribution is almost flat and the score per actor is very low. While the global stability depends on only a few actors, local stability is evenly distributed over the network and virtually independent from individual actors.

Table 2 shows an overview of the ten most prominent actors in the water innovation network, and ranks the actors in prominence. Particularly national and publicly funded research institutes fulfill a role in this network, which may be due to the large public interest in water management in the Netherlands resulting from the low altitude of the country. The highest ranked multinational (Shell RTC) is only in seventh place. Some of the actors concentrate their activities mainly on one subfield (Maritime technology, Delta technology, Water technology), other actors are equally active in multiple subfields, but almost all prominent actors bridge between different subfields. The results show that most actors participate in multiple consortia over multiple years. Particularly Deltares (WL | Delft Hydraulics) (36 consortia over 23 years) and RWS Waterdienst (RIZA) (31 consortia over 20 years) are very active in this network. For

Figure 5: Stability Prominence of Network Members



318 network members.

Table 2: Top 10 Most Prominent Actors

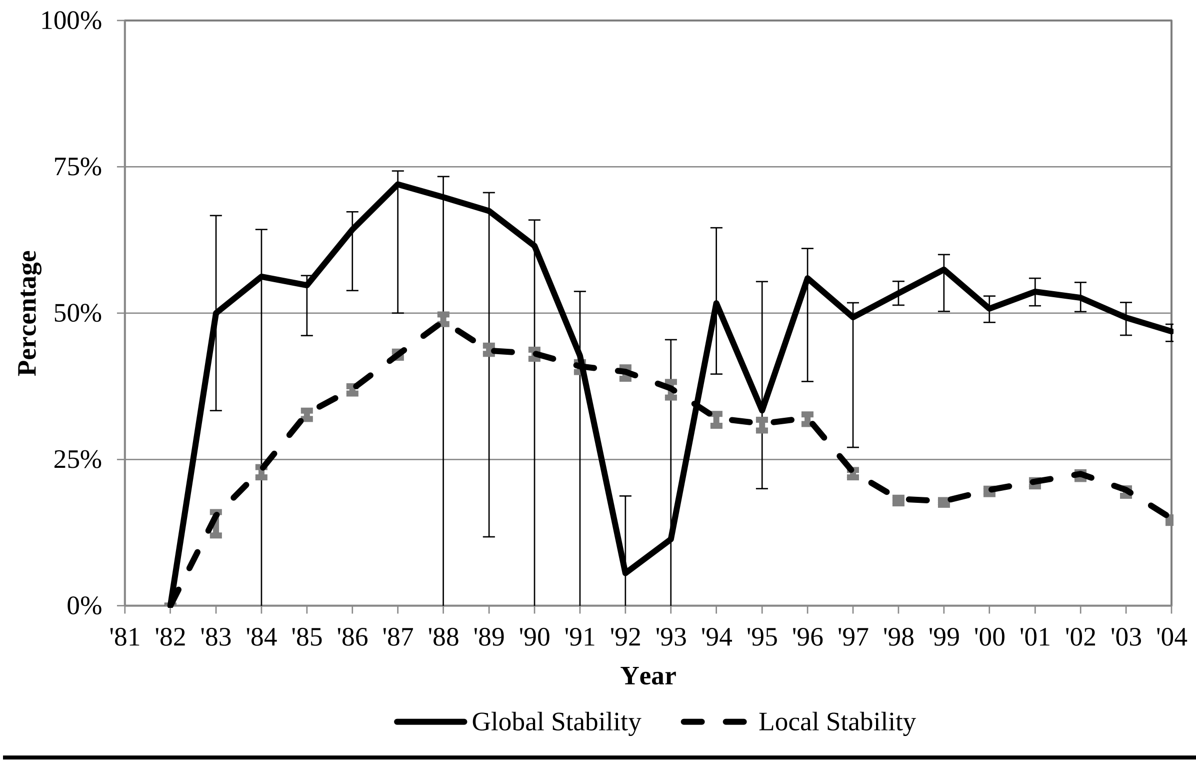
Rank	Name	Field	Consortia	Years	Global Stability Prominence		Local Stability Prominence	
1	Deltares (WL | Delft Hydraulics)	Mixed	36	23	-0.178	(0.273)	0.000	(0.000)
2	Rijkswaterstaat	Delta	12	20	-0.043	(0.130)	-0.002	(0.004)
3	RWS Waterdienst (RIZA)	Mixed	31	20	-0.038	(0.130)	0.000	(0.001)
4	Deltares (GeoDelft)	Mixed	7	17	-0.036	(0.120)	-0.003	(0.005)
5	MARIN	Maritime	13	20	-0.019	(0.053)	-0.003	(0.005)
6	RWS Waterdienst (RIKZ)	Delta	13	19	-0.018	(0.031)	-0.001	(0.003)
7	Shell Research and Technology Centre	Maritime	8	20	-0.012	(0.022)	-0.001	(0.003)
8	RIVM	Water	13	21	0.011	(0.050)	-0.003	(0.005)
9	Grontmij Nederland	Water	3	6	-0.011	(0.065)	0.000	(0.003)
10	DHV Milieu & Infrastructuur	Delta	4	11	0.010	(0.038)	-0.001	(0.001)

Ranked on global stability prominence; Standard deviation in parenthesis.

two out of ten actors the global stability increases in case these actors drop out of the network. For all other prominent actors, the global stability decreases if they drop out of the network. The standard deviations for prominence show strong variation over the years, particularly for the four most prominent actors. In the following, we discuss these temporal fluctuations in more detail.

The next issue we address is the impact of the single most prominent actor on the field network stability (Figure 6). The results show that the local stability increased until 1988 and then decreased gradually. The local stability hardly changed due to the exclusion of the most prominent actor. The global stability increased strongly during the first years of the network and will remained high until 1992 when the network did fall apart, to recover again a few years later. It turns out that, in the years preceding the network collapse of 1992, the global stability of the network became more sensitive to the exclusion of the most prominent actor. First, the global stability of the network got more sensitive to the exclusion of Deltares (WL | Delft Hydraulics), which acted as a central connector between the subfields Delta and Maritime technology. As a result, the sensitivity of the network increased between 1987 and 1988 from 22% to 86% stability reduction if Deltares (WL | Delft Hydraulics) would get excluded. However, Deltares (WL | Delft Hydraulics) continued its connector position in a stable fashion and the network did not collapse at this time. Second, between 1989 and 1991 the network became increasingly sensitive to the exclusion of Rijkswaterstaat (from 1% to 48%) and RWS Waterdienst (RIZA) (from 1% to 33%). These developments were accompanied by an internal reorganization of RWS Waterdienst (RIZA), the dissolution of the direct tie in the network between Deltares (WL | Delft Hydraulics) and RWS Waterdienst (RIZA), and eventually the dropout of Rijkswaterstaat in 1992 which made the network disintegrate. Between 1994 and

Figure 6: The Sensitivity of Network Stability to the Exclusion of the Single Most Prominent Actor



23 network years; error bars represent the change in network stability per year due to the exclusion of the single most prominent actor.

1995 RWS Waterdienst (RIZA) also dropped out of the network. When RWS Waterdienst (RIZA) subsequently returned to the network in 1996, it immediately continued its connector position between the subfields Delta and Water technology and the water innovation network recovered again, but compared to the period before 1992 the network stability was hardly sensitive to the exclusion of the most prominent actor. Our interview results do confirm that the internal reorganizations of these organizations, in particular the redefined regulatory task of RWS Waterdienst (RIZA), as further discussed by Hoogland (2010), fulfilled a central role in the development of this water innovation network.

5.5.4 The Influence of Local and Global Stability on the Innovation Success of R&D Consortia

In this section, we examine the influence of the dynamics of the field network on the consortia success. We focus in particular on the effect of local and global stability on the innovation success. Approximately 56% of the consortia achieves innovation success[24].

Table 3: Consortium Level Descriptive Statistics and Correlations

	Variables	Mean	SD	1	2	3	4	5
1	Consortium Success	0.557	0.499	1.000				
2	Consortium Size	5.608	3.002	0.008	1.000			
3	Consortium Duration	4.485	1.234	-0.121	0.139	1.000		
4	Allocated funding (100k)	3.307	2.110	0.015	0.290**	0.443***	1.000	
5	Researcher Quality	6.308	6.774	0.141	-0.063	-0.109	-0.033	1.000
6	Network Autocorrelation	0.494	0.288	-0.047	0.138	0.093	0.121	-0.073
7	Largest Component	0.802	0.185	-0.147	0.244*	0.049	0.114	0.273**
8	Small-worldliness	5.675	1.862	-0.126	0.146	-0.009	0.076	0.202*
9	Global Stability	0.527	0.109	-0.049	-0.052	-0.102	-0.248*	-0.082
10	Local Stability	0.270	0.100	-0.040	-0.275**	-0.252*	-0.063	-0.225*

97 consortia; † p < .100; * p < .050; ** p < .010; *** p < .001

Table 3: Consortium Level Descriptive Statistics and Correlations [Continued]

	6	7	8	9	10
6	1.000				
7	0.389***	1.000			
8	0.332***	0.850***	1.000		
9	-0.043	0.294**	0.442***	1.000	
10	0.113	-0.261**	-0.100	0.291**	1.000

[24] Based on the criteria member involvement, product development, and income achievement. The success probabilities on the criteria member involvement (77%), and product development (86%), differ compared to the score on income achievement (33%). In the robustness test section we briefly discuss separate analyses per criterion, which show that our findings predominantly relate to income achievement, i.e. the probability that consortia achieve economically viable innovation outcomes.

Table 4 shows the results of the multilevel mixed effects regression analyses with a logistic regression transformation on the probability of consortium success. We used random effects for the observation years, because a model with fixed effects would not allow testing the year variation in network structure and dynamics. Model 1 includes the control variables consortium size, consortium duration, allocated funding, researcher quality, and a network autocorrelation term. In Model 2, the network structure variables are added, largest component and small-worldliness. In Model 3, we add global and local stability. In model 4, we add the interaction term of global and local stability. The chi-square test of improvement of fit in the -2 log likelihood (Long & Freese, 2006), shows that Model 4 provides a statistically significant ($p < 0.050$) improvement of fit to the data. The results show that the quality of the executive researcher (RQ) improves the probability of consortium success (RQ = 0.112; $p < 0.050$). In addition, the effect of global stability (GS) is positive and statistically significant (GS = 37.652; $p < 0.050$), the effect of local stability (LS) is positive and marginally significant (LS = 46.806; $p < 0.100$), and the interaction effect is negative and statistically significant (GS*LS = -91.661; $p < 0.050$).

Table 4: Logit Regression of Probability Consortium Success

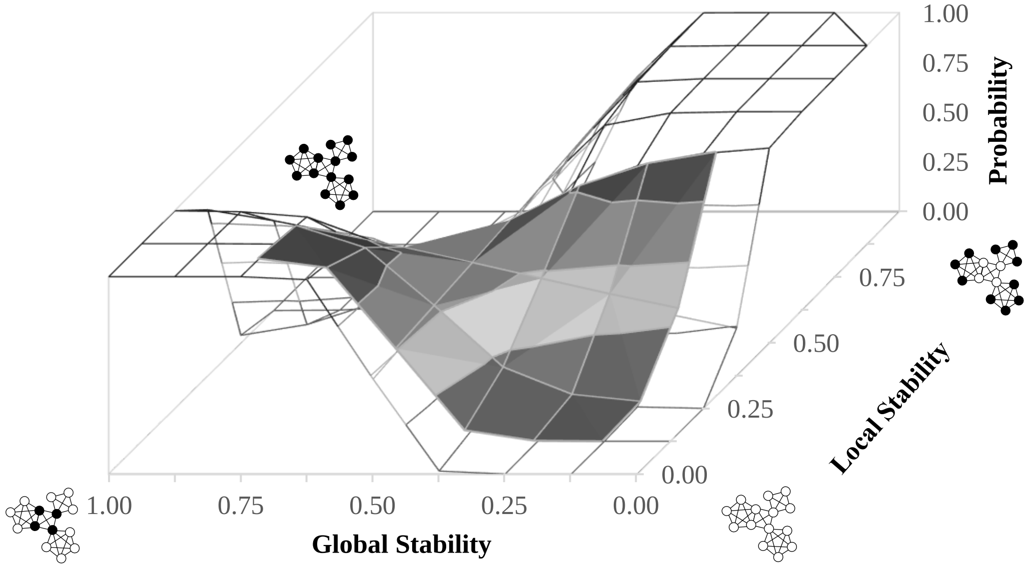
	Model 1 Consortium Success		**Model 2 Consortium Success**		**Model 3 Consortium Success**		**Model 4 Consortium Success**	
Intercept	1.313	(1.155)	2.782*	(1.368)	3.380	(2.067)	-16.915†	(10.069)
Consortium Size	0.023	(0.079)	0.046	(0.080)	0.023	(0.081)	0.007	(0.083)
Consortium Duration	-0.267	(0.215)	-0.269	(0.207)	-0.378†	(0.228)	-0.268	(0.239)
Allocated funding	0.112	(0.131)	0.099	(0.126)	0.166	(0.133)	0.236†	(0.143)
Researcher Quality	0.065	(0.047)	0.076	(0.047)	0.076†	(0.044)	0.112*	(0.050)
Network Autocorrelation	-0.640	(0.880)	-0.036	(0.927)	0.573	(1.036)	0.673	(1.068)
Largest Component			-2.607	(2.528)	-3.528	(2.655)	-0.923	(2.966)
Small-worldliness			0.005	(0.226)	-0.058	(0.244)	-0.246	(0.273)
Global Stability					3.257	(2.908)	37.652*	(17.112)
Local Stability					-3.957	(3.165)	46.806†	(24.838)
Global * Local Stability							-91.661*	(44.658)
Intra-class correlation	0.048	(0.096)	0.005	(0.083)	0.000	(0.000)	0.000	(0.000)
Log Likelihood	-62.958		-61.509		-60.536		-58.274	
df	9		11		13		14	
Chi^2	7.290		2.900		1.950		4.520*	

97 consortia; Standard errors in parenthesis; † $p < .100$; * $p < .050$; ** $p < .010$; *** $p < .001$; controlled for subfield.

Figure 7 gives a graphical representation of the average marginal effects of local and global stability on the probability of consortium success. Such a graphical representation is particularly recommended for interaction effects in non-linear models (Hoetker, 2007; Karaca-Mandic et al., 2012), because of the interdependency of effects in logistic regression models. The surface represents observed range of both variables; the wireframe represents the predicted effect. We observed low (0.125), moderate (0.500) and high (0.750) levels of global stability, but only low (0.125) and moderate (0.500) levels of local stability. Figure 7 shows that the probability of consortium success is lowest in networks that either combine low levels of global stability (0.125) with low levels of local stability (0.125) (Volatility: p(Success) = 0%), or in networks that combine high levels of global stability (0.750) with relatively high levels of local stability (0.500) (Stable small-world: p(Success) = 20%). Networks with moderate levels of global and local stability (0.500) have a moderate probability of consortium success (p(Success) = 58%). The probability of consortium success is highest in networks that either combine low levels of global stability (0.125) with relatively high levels of local stability (0.500) (Recombining clusters: p(Success) = 95%), or in networks that combine high levels of global stability (0.750) with low levels of local stability (0.125) (Stable core-flexible shell: p(Success) = 100%). Bonferroni adjusted post hoc tests on the marginal effects confirmed the statistical significance ($p < 0.050$) of the discussed differences.

To test the robustness of our findings, we used alternative time windows for the network variables computed over the full consortium duration, instead of the consortium start year. The results are comparable to the main model. In addition, we also achieved comparable results after controlling for the repeated collaboration experience and level of participation of the consortium members. Finally, we conducted separate analyses for the three dimensions of consortium success. We found no statistical significant effects of global and local stability on the probability of relational success (member involvement), and technological success (product development). For economic success (income achievement) on the other hand, the results are

Figure 7: Marginal Effects Global and Local Stability on the Probability of Consortium Success



97 consortia; surface represents observed range, wireframe represents predicted effect.

similar to the main model. This implies that our model mainly predicts the probability that consortia achieve economically viable innovation outcomes.

5.6 Discussion & Conclusion

The major goal of this study was to synthesize small-worldliness and stability of actor position especially of the central connectors in order to advance our understanding of organization and field level dynamics in innovation networks. Several observations determine the theoretical and empirical relevance of this chapter. First, prior research has demonstrated the importance of small-world structures for innovation networks (e.g. Burt, 2005; Schilling & Phelps, 2007; Sullivan et al., 2014; Uzzi & Spiro, 2005). Second, there are only very few studies that did examine the genesis of such networks (Baum et al., 2003; Davis et al., 2003; Gulati et al., 2012). Third, to our knowledge there are no studies that combine both antecedents and outcomes of small-world structures. Particularly studies that examine the relation between dynamics at the organization and the network level are rare due to the significant data requirements for such studies, whereas we could meet these data requirements (Moliterno & Mahony, 2010; Raab et al., 2013). In order to contribute to the literature on innovation networks and small-world structures, we investigated firstly the antecedents for organizational level dynamics with interview data and quantitative data particularly the positional stability of actors; secondly the relation between prominence of individual actors and field network stability; and thirdly the innovation performance implication of local and global stability in the field network. More specifically, we examined to what extent the stability of the central connectors in a water innovation network in the Netherlands result in the development of a stable core-flexible shell structure at the network level, which in turn increases the probability of innovation success of the involved R&D consortia.

5.6.1 Antecedents for the Positional Stability of Actors

Our interview results revealed four antecedents that are particularly important in explaining positional stability of actors in the innovation network. Interviewees argued that the intensity of inter-organizational collaboration is a typical developmental process, and increases only gradually. Simultaneously, our findings show that productive network relations are very sensitive to sudden institutional changes, organizational changes, and environmental shocks. Especially the network disruption in 1992 – which was preceded by a combination of increased network sensitivity for the exclusion of the most prominent actor and an internal reorganization by one of the most central connectors in the network – had major implications for the network development in general and the position and stability of individual actors in particular. Due to this industry event the network disintegrated, individual organizations lost their connector position or dropped out entirely from the network, and as a consequence the consortium success of the involved consortia declined. These qualitative findings were congruent with our quantitative estimation of organization level dynamics. Our findings confirmed that this disruptive event – i.e. the co-occurrence of institutional changes, organizational changes and environmental shocks – strongly reduced the positional stability of the network members, particularly the central connectors. Besides a contribution to the understanding of the genesis of small-world structures as well as organization and field network level dynamics in innovation networks (Baum et al., 2003; Davis et al., 2003; Gulati et al., 2012; Rosenkopf & Padula, 2008) our findings also show that the influence of organizational agency on field network developments (e.g. Ahuja et al., 2012) is relatively limited in comparison to the impact of industry events (Madhavan et al., 1998; Schilling, 2015). The stability of the complete field network and the positional stability of individual network members are hardly impacted by the organizational actions of the overwhelming number of these members, but strongly affected by industry events that affect the central connectors in the network.

Proposition 1: Industry events matter more for the positional stability of actors in the field network relative to the actions of the individual agents.

5.6.2 The Relation between Prominence of Individual Actors and Field Network Stability

Does this finding imply that individual actors do not matter for the stability of a field networks at all. Considering the results of our findings on the relation between prominence of individual actors and field network stability one can oppose this claim. First, it turns out that the prominence of organizations – i.e. the impact that actors have on network developments – is heterogeneous. The positional stability of actors in a peripheral position has hardly any influence on the stability of the field network, whereas positional stability of the most central connectors has a very strong influence on the stability of the complete field network. We call these central and stable connectors the ‘nuclei’ of the network. When, for whatever reason, a nucleus is grabbed out of the network, the complete field network is likely to disintegrate. A closer inspection of the connectors in our model showed that there are actually two types of connectors: between-field connectors, and within-field connectors. In line with Gould and Fernandez (1989) we argue that a network often includes different subgroups or fields of expertise, in our study the subfields Maritime technology, Delta technology, and Water technology. The position of a connector can vary in the sense that it connects multiple actors from the same subfield or from different subfields. Additional analysis show that particularly organizations that connect consortia in different subfields –Between-Field Connectors (BFC) – have a central role in the functioning and development of the Water innovation network, while the influence of Within-Field-Connectors (WFC) is only minor. For now it is clear that the positional stability of individual actors in the field network does not add up one-to-one to field network stability, as some actors are much more prominent than others.

Proposition 2: The prominence of individual actors is heterogeneous. Between-field connectors have more influence on the development of innovation networks than within-field connectors and peripheral actors.

In this study, we introduce a temporal perspective on small-world structures. We build on prior research that examined organization and field network level dynamics of small-world structures (e.g. Baum et al., 2003; Davis et al., 2003; Gulati et al., 2012), and we extend this research by exploring the stability and flexibility of structurally differentiated actors (connectors versus peripheral actors) in the network. Previous research applied a similar approach to examine performance implications of tie stability (e.g. Baum et al., 2012; Soda et al., 2004), and membership turnover (Sytch & Tatarynowicz, 2014). But to our knowledge this study is the first that investigates the distribution of stability and flexibility over the core and periphery of the field network over time. Because technological risks are high and time horizons long, small-world dynamics offer important advantages for the management of innovation networks, as they provide ways to balance redundant and non-redundant information via local and global ties. (Das & Teng, 2002; Lavie et al., 2010; Ring et al., 2005). We explore the distribution of local and global stability as potential sources for new resource inflows (Sytch & Tatarynowicz, 2014; Uzzi, 1997) and for the preservation of R&D experience (Borgatti & Cross, 2003) over the core and periphery of the network. This temporal perspective is particularly applicable to networks of organizations participating in R&D consortia, because these consortia are time bound by the lifespan of the underlying projects, and hence, the network structure is fundamentally dynamic. This implies that organizations have to repeat their collaborations over multiple consortia to maintain their network position and stability. Our analysis has shown that repeated collaboration of the central connectors can both provide a stable core to the network, and attract new entrants that safeguard the flexibility of the network.

Proposition 3: Repeated collaboration of the central connectors has a positive effect on the development of a stable core-flexible shell structure in the network.

5.6.3 The Influence of Local and Global Stability on the Innovation Success of R&D Consortia

Inter-organizational collaboration in innovation networks entails the alignment of multiple favorable conditions (e.g. Adler et al., 1999; Tushman & O' Reilly, 1996). Firms both have to collect non-redundant resources (e.g. Burt, 2005; Powell et al., 1996), and have to build mutual trust and organizing capacity to transmit these new insights (Coleman, 1988; Fleming et al., 2007; Schilling & Phelps, 2007). Sytch and Tatarynowicz (2014) argue that firms can best accomplish this ambidexterous task when they both form new ties with new partners that provide them non-redundant insights and protect them against lock-ins, and maintain established ties that provide collaborative routines, trust and knowledge sharing practices. Therefore they conclude that firms are most successful when membership turnover rates in the community are moderate rather than low or high. We extend this line of reasoning and argue that the probabilty of innovation success is highest when stability and flexibility is balanced across the network (Lavie et al., 2010; Schreyögg & Sydow, 2010). Networks that are either characterized entirely by flexibility or entirely by stability might either face a lack of non-redundant information or a lack of trust and organizing capacity, and therefore will have a lower probability of innovation success compared to networks that balance stability and flexibility. Our results demonstrate that networks that have a moderate level of stability both in the core and the periphery have a higher probability of innovation success compared to completely stable or flexible networks. Results from additional analyses require further specification of this finding, as we found that networks in which either the core or the periphery is highly stable, while the other part is highly flexible, or even volatile, outperformed innovation networks with moderate stability in core and periphery. In case new entrants and longstanding members both concentrate at the same part of the network – i.e. network stability is moderate both in the core and the periphery – the buildup of joint routines and practices might still be frustrated by the new entrants. Therefore, we conclude that R&D consortia in networks in which stability and flexibility is balanced across the core and periphery of the network have a higher probability of innovation success, compared to R&D consortia in networks in which the level of stability in both the core and periphery is either low, moderate, or high.

Proposition 4: Networks with a combination of stability and flexibility in their core and periphery have a higher probability of innovation success compared to networks with either complete flexibility or complete stability in both the core and the periphery.

Stability and flexibility can be balanced across the networks in two distinct manners: either by local stability in the periphery in combination with flexible bridges between these clusters (recombining clusters), or by a stable core surrounded by a flexible shell of peripheral actors. For innovation networks, the latter (stable core-flexible shell structures) is preferable, because in such networks, the stable core can provide stability, preservation of experience, and knowing who knows what (Borgatti & Cross, 2003), and legitimacy to the network (Human & Provan, 2000), which in turn attracts new entrants (Barabási et al., 2002; Powell et al., 2005) that bring non-redundant information to the network. Conversely, networks characterized by recombining clusters – i.e. stable consortia in the periphery with flexible bridges between these consortia – the involved consortia might become increasingly inclined to keep their knowledge and resources within the consortium. In this situation Borgatti and Cross (2003) refer to a lack of transactive memory and a lack of stable relations between the consortia to facilitate trust building and mutual knowledge exchange. In the end, local stability and global flexibility can cause increasing competition between consortia in the network (Doz & Hamel, 1998; Gomes-Casseres, 1996), which hampers the average innovation output of the network.

Proposition 5: A stable core-flexible shell structure in the network increases the probability of innovation success of the participating consortia.

Summarizing, this study makes two central contributions to the literature on network dynamics in general (e.g. Ahuja et al., 2012; Powell et al., 2005), and small-world structures in particular (Baum et al., 2003; Davis et al., 2003; Gulati et al., 2012). First, we showed that not only the variance in network structure over the years, but also the stability and flexibility within the network has major implications for the innovation success of the participating consortia. We introduced a taxonomy of local and global stability, and identified the importance of a stable core-flexible shell structure for the innovation outcomes of the network. With this taxonomy, we advance our understanding of network dynamics (e.g. Ahuja et al., 2012; Powell et al., 2005), and cross-level interactions between the organization, consortium, and network level (Moliterno & Mahony, 2010; Raab et al., 2013). We leave it for future research to disentangle how local and global stability over time influence the different stages of the innovation process.

Second, we demonstrate that the impact or ‘prominence’ of individual actors in the dynamics of the complete network is far from homogeneous. While the positional stability of most actors hardly has any influence on the dynamics of the field network, the fate of the complete network is contingent on the fate of a small set of central connectors. This implies that the widely discussed influence of organizational agency on network development (e.g. Ahuja et al., 2012), might be relatively limited while the impact of industry events turns out to be quite severe (Madhavan et al., 1998; Schilling, 2015). Our results also showed that the government can exert a major influence on the performance of national innovation systems, not only through subsidies (Mazzucato, 2011), but also through legislation and regulative task changes of the central research institutes, that in turn affect the functioning of the entire knowledge infrastructure. The observation that the functioning of the entire network can get disturbed due to the dropout of a single actor has far-reaching academic and practical implications. There is an urgent need for future research that advances modeling and testing of weighted organization and network level dynamics in social networks that examines the heterogeneity of actors, and its effects on network development. Such research can add considerable refinement to our understanding of the functioning of innovation networks. We stress to practitioners that a single policy interventions can have far-reaching implications that should not be overlooked. Therefore we conclude: don’t grab that nucleus!

5.6.4 Limitations

This study is not without limitations. We examined the development of a single innovation network over a period of 23 years. The results of our analyses are exploratory, while one should be cautious with the causal inference from our observations due to the relatively low number of observations. Future research should pursue an examination of the influence of industry events and central connectors in other innovation networks. Particularly a comparison between multiple networks and industry events in different settings can provide a more structured understanding of organization and field network level dynamics in innovation networks. Secondly, even though the database includes all projects funded by one of the oldest and most prominent Technology Programs for university-industry collaboration in the Netherlands, the interactions between organizations in this innovation network most likely will exceed the funded R&D projects. Our interviews made clear that our network data gives a reasonably accurate representation of the social interactions of the involved agents. We leave it for future research to make an in-depth assessment of the different networks in which individual organizations simultaneously can participate. Finally, it was not possible to fully disentangle the influence of different events that simultaneously occurred in an individual year. The causal analysis across different levels was not without limitations, given the restricted number of observations at the network level. However, despite these limitations, the results demonstrated the importance of a temporal perspective on innovation networks. We are convinced that further research on the relation between organization and field network level dynamics in innovation networks can make a valuable contribution to our understanding of the functioning of social networks in general and R&D collaborations in particular.

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APPENDIX A

We have presented a periodization of the development of the Dutch Water innovation network, that showed two periods of low connectedness (1982-1985 and 1992-1996), and two periods of high connectedness (1986-1991 and 1996-2004). To examine the robustness of this periodization, we examined the extent to which the four time periods do have a statistically significant ($p < 0.050$) effect on the field network structure, in terms of actors connected to the largest component, small-worldliness, global stability, and local stability. Table A1 shows the results of this analysis at the field network level, including descriptive statistics, correlations, and average scores per period. The scores for largest component, small-worldliness, and global stability are obviously lower in de periods 1982-1985 and 1992-1996 compared to the periods 1986-1991 and 1996-2004. However, local stability follows a different pattern and is particularly high in the periods 1986-1991 and 1992-1996.

Table A1: Descriptive Statistics and Correlations – Field Network Level

	Variables	Mean	SD	1	2	3	4	´82-´85	´86-´91	´92-´95	´96-´04
1	Largest Component	0.733	0.254	1.000				0.434	0.850	0.491	0.928
2	Small-worldliness	5.277	2.131	0.892***	1.000			3.310	6.484	2.417	6.619
3	Global Stability	0.462	0.210	0.733***	0.652***	1.000		0.322	0.630	0.255	0.521
4	Local Stability	0.274	0.132	0.226	0.041	0.461*	1.000	0.143	0.427	0.351	0.210

23 network years; average score per period; † $p < 0.100$; * $p < 0.050$; ** $p < 0.010$; *** $p < 0.001$.

To test the statistical significance of these differences, we conducted regression analyses with the periods as predictor and the network structure variables as outcomes (Table A2). The period 1996-2004 functions as reference category. The results largely confirm the previous observations, as the scores for largest component, small-worldliness, and global stability are statistically significant ($p < 0.050$) lower in de periods 1982-1985 and 1992-1996 compared to the periods 1986-1991 and 1996-2004, while the local stability is statistically significant ($p < 0.050$) higher in the periods 1986-1991 and 1992-1996 compared to the periods 1982-1985 and 1996-2004. Bonferroni adjusted post hoc tests on the marginal effect confirm the robustness of the results. We also examined the level of fragmentation and the network size over the four periods. The results show that in the two periods of high connectedness (1986-1991 and 1996-2004) the fragmentation is low and the network attracts statistically significant ($p < 0.050$) more actors compared to the other two periods. Additional analyses on the small-worldliness show that particularly the clustering coefficient fluctuates over the four periods, while the average path length remains reasonably constant over the whole observation period. The results confirm the robustness of our initial periodization and show that the connectedness, small-worldliness and global stability rise, fall, and recover during the observation period, while the local stability follows a distinct pattern.

Table A2: Regression Analyses of Dynamics of the Field Network Structure as a Function of Time

	Model 1 Largest Component		**Model 2 Small-worldliness**		**Model 3 Global Stability**		**Model 4 Local Stability**	
Intercept	0.928***	(0.046)	6.619***	(0.396)	0.521***	(0.055)	0.210***	(0.025)
´82-´85	-0.494***	(0.076)	-3.309***	(0.714)	-0.199*	(0.092)	-0.067	(0.042)
´86-´91	-0.078	(0.072)	-0.135	(0.626)	0.108	(0.087)	0.217***	(0.040)
´92-´55	-0.437***	(0.082)	-4.201***	(0.714)	-0.266*	(0.099)	0.141**	(0.045)
´96-´04 (ref.)								
Model fit (F)	19.680***		17.270***		5.720**		16.640***	
R^2	0.747		0.7317		0.4617		0.714	

23 network years; standard errors in parenthesis; † $p < 0.100$; * $p < 0.050$; ** $p < 0.010$; *** $p < 0.001$.

APPENDIX B

For validation purposes we applied a combination of logistic and OLS regression analyses to explore the extent to which the positional stability of individual actors can be attributed to some of the antecedents distinguished by Ahuja et al. (2012), Madhavan et al. (1998), and Schilling (2015). The unit of analysis is the network member's positional stability in a given year. This exploration includes the actor's connectedness to the largest component, small-worldliness, global stability (for connectors only) and local stability (for peripheral actors only). First, an individual organization can either be connected (1) or not connected (0) to the largest component in the network. Second, we measured the small-worldliness as a function of the clustering coefficient and the average path length of individual organizations, in line with the work of Gulati et al. (2012). The small-worldliness can only be computed for organizations connected to the largest component (1500 out of 1820 observations). Third, global stability can only be computed for organizations in a connector position (326 out of 1820 observations) and refers to the percentage of prior years in which this actor has participated in the network. Fourth, local stability can only be computed for organizations in a peripheral position (1491 out of 1820 observations) and refers to the percentage of prior years in which this actor has participated in the network. We model these four actor positions as a function of the actor's position in the previous year, the local and global stability of the complete field network in the previous year, and the network disruption in 1992, which operationalize Ahuja et al.'s (2012) antecedents of field network dynamics. Table B1 displays the descriptive statistics and correlations.

Table B1: Descriptive Statistics and Correlations – Actor Level per Year

	Variables	Observations	Mean	SD	1	2	3
1	Consortium Leader	1820	0.196	0.397	1.000		
2	Largest Component member (t-1)	1820	0.824	0.381	-0.023	1.000	
3	Small-worldliness actor (t-1)	1500	6.300	2.276	0.028	.	1.000
4	Global Stability actor (t-1)	326	0.531	0.350	0.047	0.554***	-0.255***
5	Local Stability actor (t-1)	1491	0.291	0.267	0.001	-0.127***	-0.061*
6	Global Stability network (t-1)	1820	0.521	0.150	-0.004	0.221***	0.405***
7	Local Stability network (t-1)	1820	0.286	0.109	0.014	-0.049*	-0.083**
8	Disruption	1820	0.028	0.165	0.000	-0.201***	-0.219***

† $p < 0.100$; * $p < 0.050$; ** $p < 0.010$; *** $p < 0.001$.

Table B1: Descriptive Statistics and Correlations - Actor Level per Year [Continued]

	4	5	6	7	8
4	1.000				
5	.	1.000			
6	0.182**	0.140***	1.000		
7	0.045	0.361***	0.342***	1.000	
8	-0.229***	0.070**	-0.106***	0.192***	1.000

In order to examine the connectedness to the largest component, we applied a random effects logistic regression analysis, because connectedness is binary. A Hausman test showed that a model with actor level fixed effects did not fit better to the data. For the other three dependent variables (small-worldliness of the actor, global stability of actors in a connector position, and local stability of actors in a peripheral position) we applied regression analyses with actor level fixed effects. Hausman tests showed that models with fixed effects fit the data better than models with random effects. We controlled for subfield and the role (consortium leader) in the model with random effects.

Our results broadly confirm the explanatory value of the antecedents for field network dynamics of Ahuja et al. (2012). Results show that the past position in the previous year is a statistically significant ($p < 0.050$) predictor of the position in the next year. This implies that actors are inclined to maintain their current network position, which points towards inertia in the network (Ahuja et al., 2012; Li & Rowley, 2002). Furthermore, the global stability of the complete network increases both the probability that actors subsequently become connected to the largest component (+3.114; $p < 0.050$), and the small-worldliness scores of actors (+6.009; $p < 0.050$), and the global stability of connectors (+0.418; $p < 0.050$), and the local stability of peripheral actors (+0.064; $p < 0.050$). Thus, global stability of the central connectors increases the stability and connectedness of both peripheral actors and connectors, i.e. all actors become connected to the core of the network, which is indicative of preferential attachment (Barabási et al., 2002; Powell et al., 2005). The local stability of the network, on the other hand, has a negative but statistically insignificant effect on the connectedness to the largest component and small-worldliness scores of actors, a negative and statistically significant effect on the global stability of connectors (-0.400; $p < 0.050$), and a positive effect on the local stability of actors (+0.449; $p < 0.050$). Thus, local stability of the complete field network reduces the stability of global connectors and simultaneously increases the stability of local periphery. We infer from this observation that local stability in the periphery stimulates the disintegration of the network into unconnected subgroups, which suggests competition among the local consortia (Doz & Hamel, 1998; Gomes-Casseres, 1996). Finally, the network disruption in 1992 had a statistically significant negative effect on the actors’ connectedness to the largest component (-3.298; $p < 0.050$), small-worldliness (-3.086; $p < 0.050$), and global stability of the connectors (-0.440; $p < 0.050$), and a positive marginally significant effect on the local stability in the periphery (+0.043; $p < 0.100$). In line with previous research (e.g. Gulati et al., 2012; Schilling, 2015), our results show that industry events – in our case the co-occurrence of institutional changes, organizational changes and environmental shocks – have a strong effect on the disintegration of the network. Table B2 shows the results. The robustness of the results is confirmed with Bonferroni adjusted post hoc tests on the marginal effects.

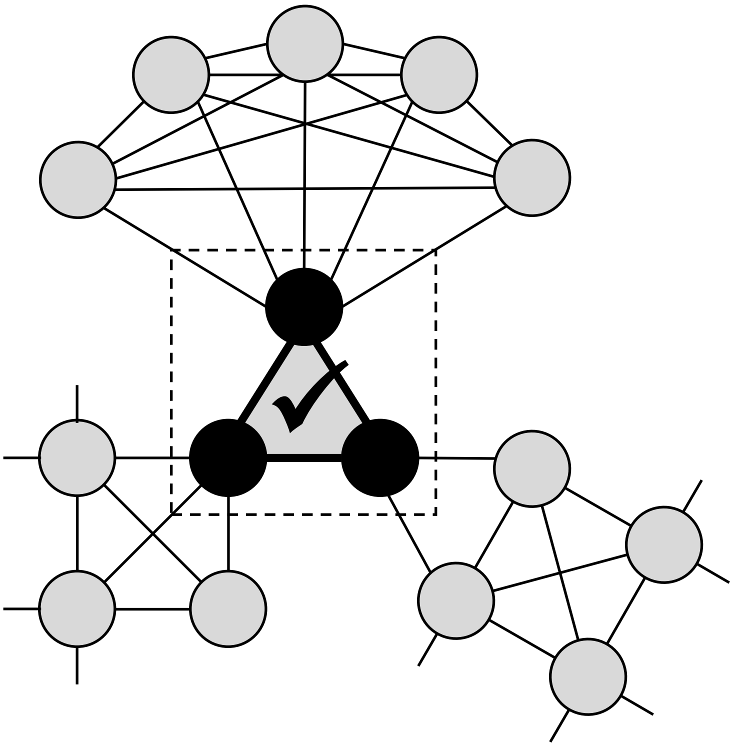
Table B2: Regression Analyses on the Positional Stability of Actors

	Model 1 Largest Component membership		**Model 2 Small-worldliness actor**		**Model 3 Global Stability actor**		**Model 4 Local Stability actor**	
Intercept	-0.282	(0.388)	3.386***	(0.276)	0.293**	(0.099)	0.048*	(0.024)
Consortium Leader	-0.173	(0.321)						
Past position of actor								
Largest Component member (t-1)	2.574***	(0.227)						
Small-worldliness actor (t-1)			0.132***	(0.014)				
Global Stability actor (t-1)					0.179**	(0.051)		
Local Stability actor (t-1)							0.499***	(0.019)
Past network structure								
Global Stability network (t-1)	3.114***	(0.597)	6.009***	(0.404)	0.418**	(0.139)	0.064*	(0.028)
Local Stability network (t-1)	-0.891	(0.960)	-0.999†	(0.550)	-0.400*	(0.187)	0.449***	(0.051)
Disruption	-3.298***	(0.425)	-3.086***	(0.374)	-0.440***	(0.093)	0.043†	(0.022)
Intra-class correlation	0.416***	(0.069)	0.493***		0.471***		0.521***	
Log Likelihood	-542.497		-2501.982		54.727		1129.365	
df	10		8		8		7	
Chi^2	63.330***		83.160***		28.200***		4.700*	
Number of observations	1820		1500		326		1491	
Model	Random effects Logit		Fixed effects Regression		Fixed effects Regression		Fixed effects Regression	

Standard errors in parenthesis; † p < 0.100; * p < 0.050; ** p < 0.010; *** p < 0.001; controlled for subfield.

CHAPTER 6

TO REPEAT OR NOT TO REPEAT: CONCLUSIONS



6.1 INTRODUCTION

Dutch universities are among the most innovative universities in the world, thanks to strong collaboration with industry (CWTS, 2015; Times Higher Education, 2015). However, the knowledge infrastructure between universities and industry heavily depends on public financing and governmental coordination (Hage & Meeus, 2006; Mazzucato, 2011). This dissertation explored the dynamics and success of university-industry collaboration in R&D consortia granted by one of the oldest and most prominent Technology Programs in the Netherlands. With an annual budget of more than € 100 million (STW, 2015), the Technology Program has granted a few thousand R&D consortia since it started in 1981 and is still ongoing. This dissertation focussed on repeated collaborations between university and industry partners in these R&D consortia. We aimed to develop a temporal lens that sheds more light on social embeddedness of the participants in the consortia, on the role of individual organizations and state interventions in the development of the wider innovation network, and on the organization and consortium innovation success.

This dissertation started with the following observations which were derived from the literature. Firstly, prior research has widely demonstrated the importance of inter-organizational collaboration for conducting R&D (e.g. Hagedoorn & van Kranenburg, 2003; Meeus, Oerlemans, & Kenis, 2008; Powell, Koput, & Smith-Doerr, 1996; Schilling & Phelps, 2007). Secondly, organizations often times align their joint R&D activities through temporary R&D consortia (Das & Teng, 2002; Doz, Olk, & Ring, 2000; Evan, 1993; Oerlemans & Meeus, 2009). Thirdly, collaboration in temporay R&D consortia can provide access to heterogeneous resources, opportunities to shorten production cycles and time to market (Doz & Hamel, 1998; Gilsing, Lemmens, & Duysters, 2007; Gomes-Casseres, 1996), and can strengthen the flexible side of a firm's R&D-portfolio (e.g. Adler, Goldoftas, & Levine, 1999; Liebeskind, Oliver, Zucker, & Brewer, 1996). Fourthly, inter-organizational collaboration in R&D consortia and innovation networks is not static, but transforms with the relational choices of organizations and with the wider networks dynamics (e.g. Gulati & Gargiulo, 1999; Powell, White, Koput, & Owen-Smith, 2005). These dynamics are particularly prevalent when the innovation networks are shaped by temporary R&D consortia (Bakker, Boroş, Kenis, & Oerlemans, 2013; Bakker & Knoben, 2015; Das & Teng, 2002) that offer opportunities to spread risks associated with longer term R&D trajectories (Das & Teng, 2002; Lavie, Kang, & Rosenkopf, 2010; Ring, Doz, & Olk, 2005). However, little is known about the temporal dynamics of collaboration in R&D consortia (e.g. Ahuja, Soda, & Zaheer, 2012; S. Zaheer, Albert, & Zaheer, 1999), particularly the cross-level interactions between the organization, consortium, and network levels (Brass, Galaskiewicz, Greve, & Tsai, 2004; Moliterno & Mahony, 2010; Raab, Lemaire, & Provan, 2013; A. Zaheer, Gözübüyük, & Milanov, 2010).

In response to these previous calls for time-sensitive theories of collaboration (e.g. Albert, 2013; Ancona, Goodman, Lawrence, & Tushman, 2001; Gersick, 1991; S. Zaheer et al., 1999), this dissertation introduces a temporal perspective on repeated collaboration in R&D consortia. We argued that organizations that repeat their collaborations through multiple temporary R&D consortia, extend the duration of their relations with the same partners, and hence, create some stability of their relationships even within the flexible form of the R&D consortia. We developed a series of dynamic models to refine existing models of antecedents and consequences of repeated collaboration in R&D consortia. Our temporal perspective allowed us (I) to disentangle distinct time utilization strategies of organizations in R&D consortia; (II) to shed more light on the explanatory mechanisms of embeddedness theory including a temporal lens; (III) to examine the importance of the timing of actual resource inputs for innovation success; and (IV) to explore the distribution of stability and flexibility across the core and the periphery of the field innovation network. In this chapter we present the main conclusions of the dissertation and provide an answer to the general research question: *To what extent does past social embeddedness influence the timing of repeated ties in R&D consortia, and to what extent do these repeated ties influence the organization and consortium innovation success?*

6.2 Summary of the Empirical Findings

6.2.1 A Temporal Perspective on Repeated Collaboration

In Chapter 2 of this dissertation, we explored how the likelihood of repeated collaboration unfolds over time, and to what extent the timing of repeated collaboration is associated with distinct actor sets involved in the R&D consortia. Timing of repeated collaboration refers to a discrete point in time, relative to the start of the focal consortium, after which (a subset of) the members start a new consortium. We derived the baseline assumptions from embeddedness theory, more specifically Granovetter's (1985) notion of the social embeddedness of economic action. In embeddedness theory it is argued that, over time *continuing relations* (including repeated collaboration) result in social embeddedness (Granovetter, 1985), in which trust is developed, perceived opportunism declines, and actors learn about their partner's capabilities (e.g. Gulati, 1995a; Parkhe, 1993; Stuart, 2000; Uzzi, 1999). We investigated the implicit assumption in embeddedness theory that timing of repeated collaboration is homogeneous, i.e. behavior of agents is similar with respect to the timing repeated collaboration, and repeated ties mainly occurs in a sequential fashion. Obviously this homogeneity assumption causes a pattern of social embeddedness over time, particularly geared to stability, and less to renewal of partnerships (e.g. Cattani, Ferriani, Negro, & Perretti, 2008; Gulati, 1995a; Kale, Singh, & Perlmutter, 2000).

Our findings showed that the timing of repeated collaboration is anything but homogeneous and really differs over distinct stages of repeated collaboration. Closely after the consortium start R&D consortia initiate repeated ties in parallel, whereas near the consortium end R&D consortia initiate sequential repeated ties. The timing of repeated ties is associated with two distinct time utilization strategies. First, a time compression strategy, which is reflected in parallel repeated collaborations, intensifies the relationship and signals the urgency of a research objective that motivates to ramp up efforts quickly or capitalize on new opportunities. Second, a time extension strategy, reflected in sequential timing, resembles an organic maturation of knowledge and competences, by spreading out activities over an increasingly longer time period, with the extension of the relationship duration. The 'getting to know, create a safe, trustworthy environment' kind of argument of embeddedness theory (e.g. Granovetter, 1985; Gulati, 1995b), mainly applies to the time extension strategy, indicative of the development of social embeddedness over longer time periods, and not to the time compression strategy.

It turns out that organizations do not use the two time utilization strategies randomly, instead institutional logics affect the timing of repeated collaboration. Industry partners are embedded in a different institutional logic compared to university partners that makes for distinct time horizons within which R&D is supposed to deliver economic outcomes. In case of dyadic collaboration embedded in a science logic, actors are more likely to apply a time extension strategy, whereas in case of dyadic collaboration embedded in an industry logic, actors are more likely to apply a time compression strategy. Moreover, in multi-partner repeated collaborations, the prevalence of time compression and extension is equal, and hence, the effect of institutional logics is nullified. Conflicting demands for long-term stability (science logic) and short term intensification (industry logic) become united in the consortium as a social entity.

This chapter extends embeddedness theory as developed by Granovetter (1985) with a preliminary theory of the *timing* of repeated ties. We showed that actors make conscious choices with respect to the timing of repeated collaborations, i.e. actors apply substantively distinct time utilization strategies to meet the requirements of their institutional environment. One of the main scientific implications of this observation is that social embeddedness should not only be measured with the number of repeated collaborations, but also include their timing. Otherwise, findings might lead to inaccurate or even flawed conclusions.

6.2.2 Towards a Time-Sensitive Theory of Embeddedness

When conducting R&D, organizations increasingly rely on inter-organizational collaboration through R&D consortia. Via their consortia memberships, organizations become embedded in a series of R&D consortia. On their turn consortia can become embedded in the wider field network through multiple overlapping members with consortia that have a similar technical orientation. This makes that the decision with whom and when to collaborate is a vital aspect of the network strategies of organizations. According to embeddedness theory, embeddedness in social relations enables and constrains the decision with whom and when to collaborate (Granovetter, 1985; Gulati & Gargiulo, 1999). Embeddedness theory, however, does not distinguish between embeddedness effects on tie formation and on the repetition of existing ties, and implicitly assumes that effects of past embeddedness are stable over time. This means that effects of past embeddedness are equally strong for tie formation, and for repeating ties.

In Chapter 3, we introduced a time-sensitive theory of embeddedness that challenges the assumption of a stable effect of embeddedness on tie formation and tie repetition and simultaneously takes into account the effects the nestedness of actors in larger social entities, such as the consortium itself and the related field networks. In order to capture the temporal dimension of the (co-)evolution of dyads after becoming part of an R&D consortium, we extended the existing typology of social embeddedness. Next to relational, structural, and positional embeddedness (Gulati & Gargiulo, 1999; Uzzi, 1997), we introduced consortium embeddedness, defined as the position of a consortium in its network. We examined the temporal dynamic effects of past embeddedness on the likelihood of formation and repetition of inter-organizational relations through R&D consortia. In our context, a temporal dynamic effect means that the effect of past embeddedness differs for distinct stages of collaboration, i.e. the likelihood of tie formation (early stage of collaboration) is impacted more by past embeddedness than the likelihood of repeated collaboration (later stages of collaboration).

Our results showed that the effects of past embeddedness on the formation of ties differ from their effects on the repetition of ties. Relational embeddedness, i.e. prior direct experience with a potential partner, and to a lesser extent structural embeddedness, i.e. indirect information about a potential partner, increase the probability of tie formation, while the positional embeddedness of organizations has little effect. The consortium fulfills a dual role in these temporal dynamics. First, when a consortium leader and member enter into a joint R&D consortium, *the consortium as social structure* embeds the newly formed dyad and modifies the meaning of past embeddedness. From the perspective of new R&D tasks taken up in a new R&D collaboration, stored information and experience from past collaborations gets new meaning when two actors form a new tie through an R&D consortium. The new consortium serves as an additional social structure where participants develop shared norms and understandings, exchange knowledge and information, and create joint value. Consequently, the actors and their dyadic relations co-evolve and develop a new frame of reference within the consortium. Second, *the consortium as a separate social entity* simultaneously becomes embedded in the wider inter-organizational network, that on its turn offers access to additional resources and value creation opportunities to the participating organizations. Whereas information exposure for partner selection is the central mechanism for the explanation of tie formation (Granovetter, 1985; Gulati & Gargiulo, 1999), mechanisms that explain repeated collaboration might include mutual social integration, resource exchange and joint value creation.

Our observations further the development of embeddedness theory by demarcating an embeddedness theory of tie formation from an embeddedness theory of repeated collaboration. Past embeddedness has a different effect on the formation of ties and the repetition of ties, i.e. the effects of past embeddedness are fundamentally dynamic. While relational embeddedness is the strongest predictor for tie formation, consortium embeddedness turns into one of the main drivers of repeated collaboration. This implies that organizations have to give new meaning to existing social structures in order to repeat their collaborations. In turn, embeddedness theory of repeated collaboration must account for these differential effects of past embeddedness.

6.2.3 A Contingency Model of Repeated Collaboration Experience and Innovation Outcomes

In Chapter 4, we explored one of the central assumptions of network theory (Ahuja et al., 2012; Rawlings, McFarland, Dahlander, & Wang, 2015), that ties in networks are “pipes” that facilitate flows of knowledge and resources (Borgatti & Halgin, 2011; Borgatti, Mehra, Brass, & Labianca, 2009; Podolny, 2001). “Perhaps the most common mechanism for explaining consequences of social network variables is some form of direct transmission from node to node” (Borgatti et al., 2009, p. 894). However, usually the “pipes” and not the actual flows are measured in social network research. Chapter 4 hones in on this void in network studies and introduces a contingency theory of repeated collaboration in multi-partner R&D consortia, by adding the contingency ‘level of participation’ to our repeated ties model. We define ‘level of participation’ as the extent to which consortium members mobilize their resources to contribute to the consortium activities.

The motivation for this contingency model results from the observation that some prior studies have shown positive effects of repeated collaboration on the probability of innovation success, while other studies showed mixed or even contradictory results (e.g. Goerzen, 2007; Zheng & Yang, 2015; Zollo, Reuer, & Singh, 2002). Often times, inconsistent findings like these are caused by unobserved contingencies. To clarify this relation, we examined to what extent the level of participation moderates and/or mediates the relation between repeated collaboration experience and organization and consortium innovation success. We explored our contingency model at both the organization and the consortium level. This distinction of multiple levels of analysis is motivated by the fact that collaboration in R&D consortia serves at minimum two goals, that of the individual organization and the collective consortium (Cohen & Levinthal, 1989; Jones, Hesterly, Fladmoe-Lindquist, & Borgatti, 1998).

Our findings show that the contingency ‘level of participation’ both moderates and mediates the relation between repeated collaboration experience and the probability of innovation success. Organizations with moderate levels of repeated collaboration experience are more likely to participate strongly in the consortium and thereby increase their probability of innovation success (mediation), and if these organizations participate strongly, they are more likely to benefit from their resource contributions compared to organizations with low or high levels of repeated collaboration experience (moderation).

Most organizations that enter into new collaborations, first employ a wait-and-see strategy to accumulate partner-specific information and explore advantageous partnering opportunities. Then, organizations tend to select and repeat those collaborations that both have the greatest potential for innovation success and provide them the opportunity to participate strongly in the consortium. By participating strongly in the consortium, organizations ‘claim’ their stake, and voice an interest in positive outcomes, whereas organizations assuming weak participation actually abstain from such claims and opt for a role of monitoring technological developments. However, organizations should carefully time their resource contributions, as strong participation turns out to operate only within limited bandwidths of the numbers of repeated collaborations. Organizations benefit most when they engage in repeated collaboration in one or two previous consortia, while repeated collaborations in multiple consortia rather reduce the probability of organization success, even if the organization contributes strongly to the consortium activities. Organizations must first gain some experience to make well informed and targeted contributions to the consortium, and to reap the rents of their contributions. Thereafter, organizations must prevent themselves from being locked into their web of relations while these relations become obsolete and exhausted.

At the same time, consortia are most likely to achieve consortium success if they first attract both new and experienced consortium participants, and then encourage either the new members (two or three) or the experienced members to participate strongly. These observations contribute to the very recent stream of social network research (e.g. Rawlings et al., 2015) that explores the central premise that social relations facilitate actual resource transmissions between nodes (Ahuja et al., 2012; Borgatti et al., 2009). The contingency model demonstrates the importance of the timing of repeated collaborations and actual resource inputs for innovation success at the organization and consortium level. Organizations use new partnerships to gain joint collaboration experience, and repeat their collaborations to mobilize their resources to contribute to the consortium activities. Our observations demonstrate that a temporal perspective on the actual resource inputs in the consortium is the key to explaining innovation success at the organization and consortium levels. Organizational actions that enhance their own innovation success, however, do not always increase the likelihood of consortium innovation success, as this requires that only a few organizations participate strongly in the consortium. Therefore, we call for future research that further explores distinct models for organization and consortium innovation success.

6.2.4 "Don't Grab That Nucleus!"

While Chapter 4 investigated innovation success as a function of organization and consortium characteristics, i.e. the repeated collaboration experience and the level of participation of consortium members, Chapter 5 focused on the embeddedness of the organizations and consortia in the wider field network. Previous research has demonstrated that the structural characteristics of the inter-organizational network at least partially predict the probability of innovation success of the involved organizations and consortia (Powell et al., 1996; Schilling & Phelps, 2007). Particularly small-world structure facilitates innovation success (Burt, 2005; Lavie et al., 2010; Schilling & Phelps, 2007; Uzzi & Spiro, 2005). However, how dynamics at the organization level and the field network level complement small-worldliness in explaining innovation performance has been an understudied phenomenon. The aim of this Chapter 5 was to advance our understanding of the interplay between dynamics at the organization and the field network levels in innovation networks, as recently placed on the research agenda (Ahuja et al., 2012; Amburgey, Al-Laham, Tzabbar, & Aharonson, 2008; Brass et al., 2004). We examined the stability of actor positions in small-world structures, and the related field network dynamics, to provide insight in the success of innovation networks.

First, we extended Knoke and Yang's (2008) original conceptualization of 'prominence' of organizations with a dynamic understanding of the importance of actors in a field network. Our central reasoning is that the prominence of individual organizations in the development of the field network is a function of their current network position – e.g. connectors versus peripheral actors – in combination with their past positional stability. Organizations that combine a connector position with high positional stability – i.e. stable connectors – are more prominent in the development of the field network, compared to organizations that either combine a connector position with low positional stability or combine a peripheral position with high positional stability. Thus, the prominence of organizations in the development of the field network is heterogeneous. Our results showed that stable connectors are indeed the most prominent in the development of the field network, in particular when these stable connectors link different subfields in the field network.

Second, we examined to what extent the positional stability of individual actors adds up to dynamics at the field network level. Our findings showed that on the one hand, the local stability of organizations within R&D consortia is mainly a function of repeated collaborations of the individual organizations. On the other hand, global stability of the wider field network – e.g. the extent that local clusters are mutually connected by transitory shortcuts – is hardly impacted by the organizational actions of the overwhelming number of network members. Instead, industry events turn out to be decisive for the global stability of the field network. This is the case because these industry events strongly influence the positional stability of the central connectors, i.e. the bridging ties between different clusters (transitory shortcuts) in the network. We call these central and stable connectors the 'nuclei' of the network. One of the main scientific implications of this observation is that the impact of agency of individual organizations in innovation networks is clearly limited.

Third, our results demonstrated that repeated collaboration of these nuclei can result in the development of a stable core in the network that provides stability, preservation of experience, and legitimacy to the network, and attracts a flexible shell of new entrants that bring non-redundant information to the network. The distribution of stability and flexibility over the core and periphery of the network – i.e. the development of a stable core-flexible shell structure – increases the probability of innovation success of the participating consortia. However, when, for whatever reason, a nucleus is grabbed out of the network, the complete field network is likely to disintegrate. This study contributes to the literature on network dynamics in general (e.g. Ahuja et al., 2012; Powell et al., 2005), and small-world theory in particular (Baum, Shipilov, & Rowley, 2003; Davis, Yoo, & Baker, 2003; Gulati, Sytch, & Tatarynowicz, 2012; Watts, 1999) by adding a dynamic perspective with regard to the positional stability of global and local actors.

6.3 Contributions to Embeddedness Theory

This dissertation advances a temporal perspective to embeddedness theory (Granovetter, 1985; Gulati & Gargiulo, 1999). First, the results of Chapter 2 showed that the timing of repeated ties is heterogeneous. On the one hand, organizations following an industry logic are most likely to repeat their collaborations in parallel with consortia that start closely after the start of the initial consortium. On the other hand, organizations that follow a science logic are most likely to repeat their collaboration near the consortium end. These timing differences are associated with two distinct time utilization strategies with substantively different meaning. The first, a time compression strategy represents demands for gaining knowledge breadth, synergy and first mover advantages, while the second, a time extension strategy, is associated with gaining knowledge depth, learning and evaluation over time as well as feasibility. The variance of time utilization strategies indicates the underlying possibility for actors to make conscious choices with regard to developing their relationships in the field network. We therefore combine Granovetter's (1985) original approach with regard to structure and agency in embeddedness theory with Emirbayer and Mische's (1998) perspective how agency takes place in a specific temporal-relational context. At the organization level, this combination enabled us to demonstrate how actors attempt to shape and modify their own relational context over time. Examining the timing of repeated ties is of central importance to further the development of embeddedness theory, because the two time utilization strategies both serve distinctive goals and results in distinctive relational contexts.

Second, the relational actions of individual organizations add up to wider field level network dynamics (Ahuja et al., 2012). Hence, insight in the distinct timing preferences of individual organizations is crucial in understanding how choices of organizations in the network can result in field network dynamics. Organizations that repeat their collaborations in parallel consortia enhance the connectedness of the network, since the ties become embedded in multiple simultaneous collaborations. Organizations that repeat their collaborations in sequential consortia on the other hand provide stability to the network, since the collaboration is continued over multiple years keeping actors within the network. When organizations combine parallel and sequential timing of repeated collaborations, as we observed for multi-partner repeated collaboration, organizations can form a stable core within the network that is both densely connected and stable over multiple years. This stable core consists of actors that collaborate repeatedly and intensively and thus form the backbone of the network where knowledge is accumulated, but also functions as a magnet for new entrants.

Despite the importance of the agency of individual organization, results of Chapter 5 do reveal that there are clearly upper limits to its impact. We reported that the organizational actions of the vast majority of network members could enhance the local stability of organizations within R&D consortia, while these actions hardly affect the global stability of the wider field network. This is due to the fact that firstly, not every organization is equally prominent in the network dynamics, while only a few organizations are responsible for the transitory shortcuts that connect the consortia in the network. Secondly, industry events have a strong influence on the network developments. Future research on inter-organizational networks should further investigate the influence of prominence differences (e.g. Ahuja, Polidoro, & Mitchell, 2009; Granados & Knoke, 2013) and industry events (e.g. Schilling, 2015) as boundary conditions for organizational agency in field network dynamics.

Third, while organizational actions to some extent add up to network dynamics, these network dynamics simultaneously define the boundary conditions for future organizational actions (Granovetter, 1985; Gulati & Gargiulo, 1999). For a nuanced understanding of the influence of social embeddedness in the wider inter-organizational network on the relational actions of individual organizations, we incorporated dynamics at the intermediate level in our research models, that is the formation and dissolution of the consortium through which organizations form their ties. Results in Chapter 3 demonstrated that the consortium is not a random environment for the dyadic relation between a consortium leader and member, but a self-selected social structure that modifies the meaning of past embeddedness. Once the consortium leader and member form a dyad in a new consortium, past embeddedness of the dyad gets a substantially different meaning. All four embeddedness effects change considerably over time, either with the formation or with the termination of the consortium.

The consortium serves as an additional social structure, more proximate and more influential than the wider inter-organizational network in which the dyad is embedded. Consortium participants develop shared norms and understandings, exchange knowledge and information, and create joint value. One example is the convergence of the two time utilization strategies, discussed in Chapter 2, into a combined strategy at the consortium level. These observations have two central implications for embeddedness theory. First, consortia play a central role in the socialization process by which organizations give new meaning to existing social structures and the replication process by which they shape new social structures. However, consortia are time-bound social entities which temporarily embed the participating organizations, as can be seen from the strong decline in the likelihood of repeated collaboration shortly after the consortium end. A temporal perspective is key to the further development of embeddedness theory. Second, once organizations form a dyad through a consortium, explanatory mechanisms seemingly shift from information exposure for partner selection to social integration, resource exchange and joint value creation as explanatory mechanisms for repeated collaboration. The distinct temporal dynamics that we reported form new building blocks for on the one hand an embeddedness theory of tie formation theory and on the other hand an embeddedness theory of repeated collaboration.

6.4 Contributions to Theory of Innovation Networks

A central element of the research question underlying this dissertation concerned the influence of repeated collaboration on the organization and consortium innovation success. In Chapter 4, we explored the sweet spot of repeated collaborations in R&D consortia. Results showed that organizations that repeat their collaborations with the consortium leader in two or three consortia – i.e. that gained joint experience in one or two former consortia – are most likely to achieve innovation success. Organizations with more or less repeated collaboration experience have lower probabilities of innovation success. However, this sweet spot is contingent on the 'level of participation' of the particular organization, which refers to the extent to which the consortium member mobilizes its resources to contribute to the consortium activities. This contingency addresses one of the central assumptions of network theory, namely that ties in the network function as "pipes" for the transmission of some resources between the involved organizations (Ahuja et al., 2012; Borgatti et al., 2009; Rawlings et al., 2015).

Our temporal perspective on collaboration revealed that the timing of actual resource inputs is crucial for the innovation success of these organizations. Organizations that mobilize their resources to contribute to the consortium activities, signal an interest and claim a stake in innovation outcomes of the consortium. Moreover, it turns out that organizations that mobilize their resources in the second or third collaboration with the same consortium leader have a considerably higher likelihood of innovation success, compared to organizations that time their resource inputs any time earlier or later than this. Organizations that repeat their collaborations without mobilizing their resources do not increase the likelihood of innovation success. These observations add considerable refinement to our understanding of the functioning of R&D consortia (Doz et al., 2000; Ring et al., 2005). They show firstly, that the level of participation, i.e. resource inputs of the involved organizations, is a central contingency in theory of innovation networks, and secondly, the timing strategies that organizations can employ with respect to their repeated collaborations and resource inputs.

Organizational actions regarding the timing of collaborations and resource inputs do not only influence their own innovation success, but also that of the consortia in which they are involved. Resources mobilization of individual organizations might simultaneously increase their own likelihood of innovation success and hamper the consortium success or vice versa, which makes careful coordination of the activities within the consortium a necessity. The extent to which the consortium achieves innovation success is strongly related to the number of consortium members that mobilize their resources. The likelihood of consortium innovation success is highest when two or three members participate strongly, and decreases significantly when either too few or too many members participate strongly. Consortia are most likely to achieve this optimal number of strong participants when they include both experienced and inexperienced members, but strong participation of both experienced and inexperienced members can hamper innovation success. This implies that consortia must first attract both new and experienced consortium participants, and then encourage either the new members (two or three) or the experienced members to participate strongly. These observations demonstrate that explanatory mechanisms at the organization level and the consortium level can be fundamentally different. Not the experience and level of participation of an individual organization, but the composition of the consortium as a whole is of central importance for the consortium success.

Our results from Chapter 5 showed that, in addition to the level of participation within the consortium, the dynamics of the wider field network in which the consortium is embedded have a strong influence on the likelihood of consortium innovation success. The likelihood of innovation success of the participating consortia is highest when the network is characterized by a stable core-flexible shell structure. However, this structure strongly depends on the positional stability of the central connectors in the network. This implies that the relational actions of these specific organizations, and particularly the industry events that affect these organizations (Schilling, 2015), can have far-reaching consequences for the entire network. Our findings contribute to theory of innovation networks in general (e.g. Powell et al., 1996; Schilling & Phelps, 2007). We extend small-world theory in particular (e.g. Baum et al., 2003; Gulati et al., 2012; Watts, 1999), with a temporal perspective on the distribution of stability and flexibility over the core and periphery of the network. Furthermore, we explored the cross-level interactions between the positional stability of individual organization, stability of the field network, and innovation success of the involved consortia that authors have called for (Brass et al., 2004; Moliterno & Mahony, 2010; Raab et al., 2013; A. Zaheer et al., 2010). The results of Chapters 4 and 5 emphasize the importance of a temporal perspective on collaboration in R&D consortia and innovation networks.

Concluding, repeated collaboration creates a connection between past social structures and future innovation success. Social embeddedness in the wider field network provides enabling and constraining conditions to form new ties and subsequently repeat these ties. Through repeated ties, organizations develop joint collaboration experience that allows them to make targeted contributions to the consortium activities and to achieve innovation success. At the same time, organizational actions to form and repeat ties affect the wider field network in which these organizations are embedded. Organizations that repeat their collaborations, replicate and give new meaning to past social structures, while they simultaneously must attract new partners for future collaborations. Analyzing repeated collaboration is therefore key to our understanding how organizations cope with the tension in balancing flexibility and stability in their innovation portfolios. Our temporal perspective on repeated collaboration in R&D consortia revealed that the timing of repeated ties and actual resource inputs is of central importance for the innovation success of the individual organization, the consortium, and the wider field network. Hence, a temporal perspective on the interrelated dynamics at these three levels – organization, consortium, and network levels – is essential for the further development of embeddedness theory and theory on innovation networks.

6.5 Practical Implications

6.5.1 Implications for Consortium Leaders (University Representatives)

Partnering. There are different ways in which consortium leaders (university representatives in our research context) can find and attract consortium partners (representatives of industrial firms or service providers in our research context). One fruitful way is to contact prior partners with whom the consortium leader has collaborated before. Prior direct experience with industry partners increases both the likelihood that this partner will join the consortium and the ability of the regarding partner to contribute to the consortium activities. Another way for attracting new partners is by getting referrals from common partners, but our results show that these partners mostly join for a single consortium without repeating their collaboration, while R&D trajectories might take longer. Third, consortium leaders can contact organizations that are central in the field. However, it might be difficult to attract these partners in the first place, and even though central partners can provide long term benefits of collaboration with central partners, they can also use their position to search for new external opportunities abandoning the consortium. Finally, consortia connected to other consortia through overlapping members can face short-term constraints due to the external obligations of the consortium members, but in the end, these connections provide access to diverse knowledge and resources, and give fertile soils for continuing the collaboration with the consortium members.

Aligning time utilization strategies. Our results demonstrated that academic consortium leaders and consortium members, i.e. industry representatives, have different time horizons within which R&D is supposed to deliver outcomes. Academic consortium leaders are inclined to apply a time extension strategy of spreading out activities over an increasingly longer time horizon for the organic maturation of knowledge and competences. Simultaneously, industry partners within the consortium face demands for time compression, the urgency to ramp up efforts quickly or capitalize on new opportunities. One way to partially overcome this pitfall and to satisfy both science and industry demands, is to opt for multi-partner repeated collaborations instead of dyadic repeated collaborations. It turns out that repeated collaborations that involve the consortium leader and more than one of the industry partners can be timed both early after the consortium start and near the consortium end, i.e. conflicting demands for short-term intensification and long-term stability become united in the consortium as a social entity. Nevertheless, consortium leaders often times first need some joint collaboration experience with new industry partners before they can meet industrial demands to speed up and scale up. At the same time, industry partners that have gained prior experience with the consortium leader are better able to participate strongly in the consortium and mobilize their resources to contribute to the consortium activities.

Innovation success. In order to achieve consortium innovation success, consortium leaders must first attract consortium partners and second encourage these partners to participate strongly in the consortium. Our findings show that consortia are most likely to achieve innovation success, in case two or three members participate strongly. The other partners can attend the (bi-)annual consortium meetings, without further contributions beyond these meetings, and still provide critical mass, legitimacy, and monitoring abilities to the consortium. In order to achieve the optimal number of strong participants, consortium leaders should first attract both new and experienced consortium participants, but then must encourage either the new members or the experienced members to participate strongly to achieve innovation success. Consortium leaders should not encourage too many consortium members to participate strongly, in order to avoid competition and management complexities. In case all consortium leaders want to participate strongly anyhow, it is of central importance to make clear agreements about the distribution of tasks, intellectual ownership, and potential innovation outcomes, even before the consortium start. Given that consortium members are most likely to achieve innovation success at the organization level when they have repeated collaboration experience with the consortium leader in one or two previous consortia, it is preferable to encourage the moderately experienced members to participate strongly, while the new members employ a wait-and-see strategy. In this way, the consortium leader maximizes the likelihood of innovation success both at the organization and consortium level, and simultaneously the consortium leader develops a partner portfolio for future consortia. Finally, what should not be overlooked is that besides selecting and encouraging consortium members, attracting talented executive researchers (mostly PhD students) is also of central importance for the consortium innovation success.

6.5.2 Implications for Consortium Members (Industry Representatives)

Organizations can engage in R&D consortia for at least two distinct objectives. First, organizations can participate in order to get exposed to new insights and social networks, without claiming a stake in the consortium innovation outcomes. Organizations that pursue this objective can engage in a single consortium and participate relatively weakly or make merely in cash contributions. Organizations must be aware, however, that most R&D trajectories have long time horizons and that innovation success might only get achieved in the second consortium. Organizations that do not want to adapt to these time horizons can employ a time compression strategy and repeat their collaborations with other industry partners just after the start of the first consortium, aiming for spillovers beyond the boundaries of the Technology Program. Second, organizations can opt for a stake in the consortium innovation success, e.g. the human capital (e.g. PhD Employment), follow-up project with a strong utilization value, or commercialization of the consortium results (e.g. the achievement of patents, exploitation licenses, implementation of the consortium results). This second objective requires a long-term strategy that comes with strong participation in the consortium. These organizations must first gain some joint experience with the consortium leader, for instance through a first consortium. In this it is important to notice that consortium leaders that are experienced and central in the field are more likely to achieve consortium success, but do not increase the probability of organization innovation success and are more selective in their partnering compared to less central consortium leaders. Once organizations have developed repeated collaboration experience with the consortium leader in one or two previous consortia, they should participate strongly and mobilize their resources in order to achieve innovation success in the consortium. Particularly in person contributions to the consortium activities (e.g. actively participating in the research; performing analyses; as co-promoter of the PhD student; or as co-author) increase the probability of innovation success. The timing of the actual resource inputs is of central importance: organizations that mobilize their resources in the second or third collaboration with the same consortium leader (the sweet spot of repeated collaboration experience) have a considerably higher likelihood of innovation success, compared to organizations that time their resource inputs any time earlier or later than this. This implies that organizations should continuously renew their partner portfolio, replacing old ties for new ties and engaging strongly in R&D partnerships of an intermediate lifespan. Organizations that apply this timing strategy in managing their partner portfolio can get continuous access to new innovation opportunities from different R&D consortia. In addition, organizations that connect different consortia can move into the stable core of the field innovation network, which provides them with first mover advantages and opportunities to recombine non-redundant insights into new innovations.

6.5.3 Policy Implications

The consortia investigated in this research are funded by a Dutch Technology Program that fosters R&D collaboration between universities and industry. Our results have demonstrated that university partners and industry partners have different time horizons within which R&D is supposed to deliver outcomes and consequently apply different time utilization strategies, time extension versus time compression. Universities and industry partners can overcome this pitfall by gaining joint collaboration experience within multiple consortia. This implies that funding schemes should allow new industry partners in the first consortium to employ a wait-and-see strategy of ‘getting to know, create a safe, trustworthy environment’, before these partners make targeted resource contributions in subsequent consortia. It turns out that industry partners that gained moderate levels of repeated collaboration experience with the consortium leader are both more likely and more efficient in participating strongly by mobilizing their resources to contribute to the consortium activities. Hence, stimulating repeated collaborations between university and industry partners in a few consortia can enhance the innovation success of the involved member organizations and the consortia. At the same time, consortium leaders should be encouraged to attract some new partners that safeguard the inflow of non-redundant information and that over time can replace the more experienced partners once their relationship with the consortium leader gets exhausted.

Our observations at the field network level demonstrated that for the overwhelming number of network members, organizational agency is restricted to the consortium level, while a few prominent actors are of central importance for the functioning of the entire knowledge infrastructure. We call these central and stable connectors the ‘nuclei’ of the network. When, for whatever reason, a nucleus is grabbed out of the network, the complete field network is likely to disintegrate. This implies that the government can exert a major influence on the performance of national innovation systems, not only through subsidies (Mazzucato, 2011), but also through legislation and regulative task changes of the central research institutes, that in turn affect the functioning of the entire knowledge infrastructure. We stress to practitioners that a single policy intervention can have far-reaching implications that should not be overlooked. Therefore we conclude: don’t grab that nucleus!

6.6 Limitations

This research has several limitations. All investigated consortia are funded by one of the oldest Dutch Technology Programs that foster R&D collaboration between universities and industry. This implies that ‘collaboration’ in our research refers to a particular type of University-Industry collaboration through R&D consortia. These consortia carry out publicly funded R&D projects with an explicit and predefined project goal, a demarcated timeframe, and the university representative as consortium leader. Collaboration between university and industry representatives beyond the boundaries of the Technology Program is not taken into consideration in this dissertation. Moreover, our analyses are restricted to consortia whose application for research funding were granted. A committee of experts, appointed by the funding agency, assessed the applications with respect to the scientific quality and utilization value. In order to control for any unobserved historical fluctuations and field network heterogeneity we included year dummies and application area dummies in our analyses. The assessment procedure of the Technology Program and the control variables and robustness tests in our analysis reduce the likelihood of any systematic bias our results, except for an overrepresentation of high quality R&D consortia. Nevertheless, we cannot eliminate that consortium leaders and members at least partially base their decisions and actions on what they believe is expected from them by the funding agency or what they think is needed to get a future project granted.

Furthermore, the assessment procedure of the Technology Program might have caused a relative overrepresentation of high quality consortia that are reasonably successful. More than 85% of the consortia is moderately to very successful in terms of technological success (i.e. product development). This low variance explains at least partially why our models in Chapters 4 and 5 fail to explain variance in technological success. Our model mainly predicts the variance in income achievement by the consortium, i.e. the probability that consortia achieve economically viable innovation outcomes. This success probability is reasonably lower (33%) than the probability of technological success, which can be explained by the fact that achieving economically viable innovation outcomes requires the consortium to be both successful in exploring new innovations and exploiting these innovations. Our models in Chapters 4 and 5 build on ambidexterity theory (e.g. Adler et al., 1999; Tushman & O' Reilly, 1996), but focus mainly on the eventual outcome of the innovation process rather than the intermediate steps. Future research is needed that replicates our studies in other research settings in order to examine the generalizability of our findings, particularly for Chapters 4 and 5 that focus on one sector. Nevertheless, we believe that these chapters make a strong contribution to the literarture on innovation networks and provide relatively unique insights in cross-level interactions between the organization, consortium, and network level. Studies on cross-level dynamics in innovation networks are rare due to the significant data requirements for such studies, whereas we could meet these data requirements (Moliterno & Mahony, 2010; Raab et al., 2013).

Another limitation results from the fact that, like most research on social embeddedness and innovation networks (e.g. Gulati & Gargiulo, 1999; Polidoro, Ahuja, & Mitchell, 2011; Schilling & Phelps, 2007), our analyses are based on secondary data that are relatively abstract and do not contain any information about the substantive processes underlying the observed patterns. Our temporal perspective allowed for a detailed analysis of the development of relations and networks. Additionally, we conducted multiple interviews to get some guidance on the underlying mechanisms and we conducted several robustness tests to exclude alternative explanations, but quantitative examination of the underlying mechanisms is required in order to give a definitive confirmation of their workings.

6.7 Directions for Future Research

This dissertation opens several promising directions for future research. This research supports the importance of a temporal perspective on inter-organizational collaboration, as called for by several researchers (Ahuja et al., 2012; Ancona et al., 2001; S. Zaheer et al., 1999). We would like to reemphasize this call and suggest the following directions for future research. First, our research contributed to a temporal perspective on embeddedness theory by showing differential effects of past embeddedness on tie formation and repetition. We call for further exploration of this temporal perspective on social embeddedness. Research that applies such a temporal approach and monitors the relational behavior of actors over time can shed more light on the explanatory mechanisms of embeddedness theory. Such research can also contribute to a separate embeddedness theory of tie formation theory and an embeddedness theory of repeated collaboration. Second, our observations demonstrated that repeated collaboration can reflect very different time utilization strategies. Future research should examine the performance implications of the different strategies. Third, we call for research that applies a temporal perspective on inter-organizational collaboration in innovation networks, particularly the central but rarely examined assumption of network theory, that ties in a network facilitate transmissions of resources from one node to another (Ahuja et al., 2012; Borgatti et al., 2009; Rawlings et al., 2015). Our observations on the timing of actual resource inputs, i.e. the level of participation, contributes to our understanding of the performance of R&D consortia. Future research can disentangle how resource inputs influence different stages of the innovation process, can examine potential organizational anticipation on expected returns, and can explore the role of individual representatives of the organizations in the collaboration process. Research that applies a temporal lens can provide critical insights in collaboration processes in R&D consortia and innovation networks.

Moreover, our research has demonstrated the importance of investigating cross-level interactions between the organization, consortium, and network levels, which several authors have called for (Brass et al., 2004; Moliterno & Mahony, 2010; Raab et al., 2013; A. Zaheer et al., 2010). We showed that innovation success at the organization and consortium level results from distinct but interrelated collaboration processes. More research is needed that explores how resource transmissions between organizations add up to joint value creation at the consortium level. Furthermore, our observations showed that dynamics at organization, consortium, and network level are strongly interrelated. However, for most organizations, organizational agency is restricted to the consortium level, while industry events can disintegrate the entire network and disrupt the functioning of knowledge infrastructure. We call for future research that examines such cross-level interactions in relation to industry events. Particularly a comparison between multiple networks and industry events in different settings can provide a more structured understanding of organization and field network level dynamics in innovation networks. Such research can also shed more light on the boundary conditions of organizational agency in innovation networks. We are convinced that research that applies a temporal perspective on organization, consortium, and network dynamics would provide an exciting and fruitful contribution to embeddedness theory and theory on innovation networks.

6.8 Concluding Remarks

The decision 'to repeat or not to repeat' turns out to be a decision with far-reaching consequences for the success of the individual actor, the consortium in which the actor participates, and the wider network in which the actor is embedded. Careful timing of this decision is key, finding the sweet spot of repeated collaboration. However, repeated collaboration is not a solitary action, but a collective decision to create a successful future together.

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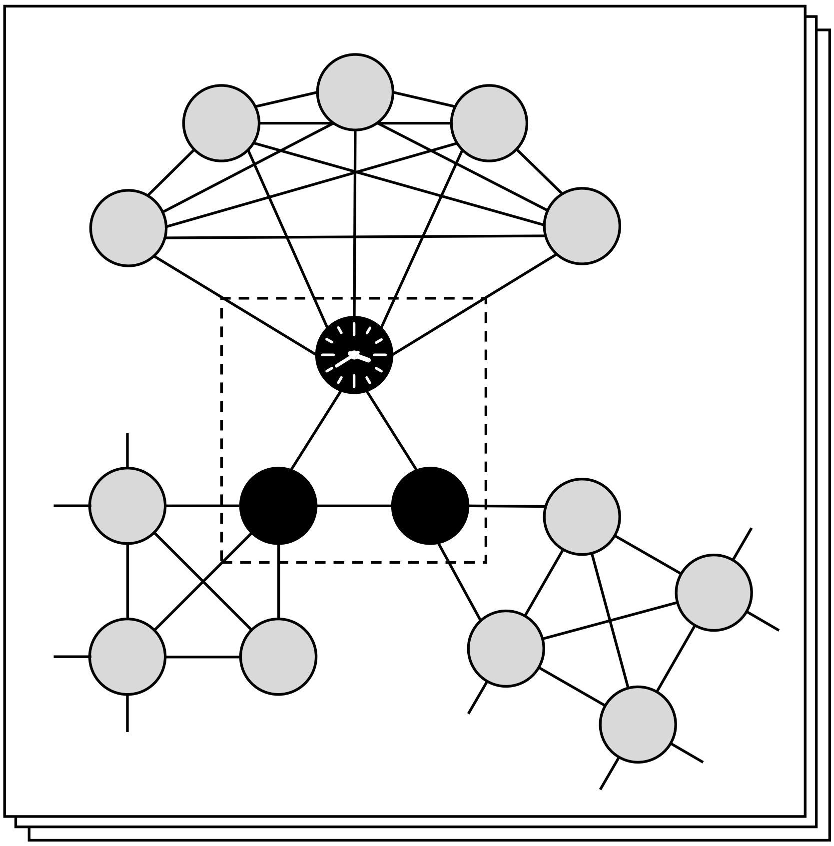
SUMMARY / SAMENVATTING



SUMMARY

Globalization, volatile markets, and rapidly changing technologies cause an increasing demand for organizations to collaborate with other organizations in joint research. Such collaborations can provide firms access to heterogeneous resources, and can reduce production cycles and time to market. One way to organize research collaboration is through R&D consortia in which universities, institutes for basic research, often fulfill a prominent role. Even though Dutch universities intensively collaborate with third parties and turn out to be among the most innovative universities in the world (CWTS, 2015; Times Higher Education, 2015), the transfer of academic knowledge to industrial firms and the utilization of basic research are far from self-evident. On the contrary, the knowledge infrastructure between universities and industry heavily depends on government interventions, both in terms of financing and proactive coordination.

This dissertation explored the dynamics and success of university-industry collaboration in R&D consortia granted by one of the oldest and most prominent Technology Programs in the Netherlands. In response to previous calls for time-sensitive theories of collaboration (e.g. Albert, 2013; Ancona, Goodman, Lawrence, & Tushman, 2001; Gersick, 1991; Zaheer, Albert, & Zaheer, 1999), this dissertation introduces a temporal perspective on repeated collaboration in R&D consortia. We argue that organizations that repeat their collaborations through multiple temporary R&D consortia, extend the duration of their relations with the same partners, and hence, create some stability in their relationships even within the flexible form of the R&D consortia. By collaborating with multiple partners in different R&D consortia over time, organizations become embedded in a wider innovation network. Hence, we attempt to develop a temporal lens that sheds more light on social embeddedness of the participants in the consortia, on the role of individual organizations and state interventions in the development of the wider innovation network, and on the organization and consortium innovation success. The general research question of this dissertation therefore is: *To what extent does past social embeddedness influence the timing of repeated ties in R&D consortia, and to what extent do these repeated ties influence the organization and consortium innovation success?*

In this dissertation, we apply a mixed methods approach and combine longitudinal analyses on collaboration in R&D consortia on the basis of secondary data with qualitative assessments of primary data from 51 interviews with consortium leaders and members. Each consortia consists of an academic consortium leader who is affiliated with one of the Dutch Universities, mostly Technical Universities or Science Departments of General Research Universities, and a user committee with an average of 4 to 5 representatives of industrial firms or service providers. We investigated 1715 consortia that were established between 1983 and 2004 and carried out R&D projects with an average duration of 4 to 5 years.

We developed a series of dynamic models to refine existing models of antecedents and consequences of repeated collaboration in R&D consortia. Our temporal perspective allowed us (I) to disentangle distinct time utilization strategies of organizations in R&D consortia; (II) to shed more light on the explanatory mechanisms of embeddedness theory including a temporal lens; (III) to examine the importance of the timing of actual resource inputs for innovation success; and (IV) to explore the distribution of stability and flexibility across the core and the periphery of the field innovation network.

First, we investigated the implicit assumption in embeddedness theory that timing of repeated collaboration is homogeneous and mainly occurs in a sequential fashion, which leads to social embeddedness over time. We explored how the likelihood of repeated collaboration unfolds over time, and to what extent the timing of repeated collaboration is associated with distinct actor sets involved in the R&D consortia. Our findings show that the timing of repeated collaboration is anything but homogeneous and differs between distinct stages of repeated collaboration. Actors make conscious choices with respect to the timing of repeated collaborations, i.e. actors apply substantively distinct time utilization strategies to meet the requirements of their institutional environment. This chapter extends embeddedness theory as developed by Granovetter (1985) with a preliminary theory of the *timing* of repeated ties.

Second, we asked whether the formation of dyads and the repetition of dyads between a consortium leader and a member are impacted differentially by their past embeddedness. Past embeddedness captures the information and experience acquired with past collaborations and largely informs the decision on whether to repeat a relation (Granovetter, 1985; Gulati & Gargiulo, 1999). Embeddedness theory, however, does not distinguish between embeddedness effects on tie formation and on the repetition of existing ties, and implicitly assumes that effects of past embeddedness are stable over time. We introduce a time-sensitive theory of embeddedness that challenges the assumption of a stable temporal effect of embeddedness on tie formation and tie repetition and simultaneously takes into account the effects the nestedness of actors in larger social entities, such as the consortium itself and the related field networks. Our results show that the effects of past embeddedness on the formation of ties differ from the effects on the repetition of ties. Whereas information exposure for partner selection is the central mechanism for the explanation of tie formation (Granovetter, 1985; Gulati & Gargiulo, 1999), mechanisms that explain repeated collaboration might include mutual social integration, resource exchange and joint value creation. This implies that organizations have to give new meaning to existing social structures in order to repeat their collaborations.

Third, we explored one of the central assumptions of network theory (Ahuja, Soda, & Zaheer, 2012; Rawlings, McFarland, Dahlander, & Wang, 2015), that ties in networks are "pipes" that facilitate flows of knowledge and resources (Borgatti & Halgin, 2011; Borgatti, Mehra, Brass, & Labianca, 2009; Podolny, 2001). Usually the "pipes" and not the actual flows are measured in social network research. We introduce a contingency theory of repeated collaboration in multi-partner R&D consortia, by adding the contingency 'level of participation' to our repeated ties model. We define 'level of participation' as the extent to which consortium members mobilize their resources to contribute to the consortium activities. Our observations demonstrate that a temporal perspective on the actual resource inputs in the consortium is the key to explaining innovation success at the organization and consortium levels. Organizations use new partnerships to gain joint collaboration experience, and repeat their collaborations to mobilize their resources to contribute to the consortium activities. Organizations must first gain some experience to make well informed and targeted contributions to the consortium, and to reap the rents of their contributions later.

Fourth, we explored the distribution of stability and flexibility across the core and the periphery of the field innovation network. We therefore synthesized small-worldliness of the innovation network (Baum, Shipilov, & Rowley, 2003; Davis, Yoo, & Baker, 2003; Gulati, Sytch, & Tatarynowicz, 2012; Watts, 1999) and the positional stability of actors to provide insight in the success of innovation networks in the Dutch Water sector. We aimed to advance our understanding of the interplay between dynamics at the organization and the field network levels in innovation networks, as recently placed on the research agenda by a multitude of scholars (Ahuja et al., 2012; Amburgey, Al-Laham, Tzabbar, & Aharonson, 2008; Brass, Galaskiewicz, Greve, & Tsai, 2004). Our results demonstrate that repeated collaboration of the central and stable connectors in the network – the 'nuclei' – can result in the development of a stable core in the network that provides stability, preservation of experience, and legitimacy to the network, and attracts a flexible shell of new entrants that bring non-redundant information to the network. The distribution of stability and flexibility over the core and periphery of the network – i.e. the development of a stable core-flexible shell structure – increases the probability of innovation success of the participating consortia. However, when, for whatever reason, a nucleus disappears or is "grabbed out" of the network, the complete field network is likely to disintegrate.

In sum, we can state that repeated collaboration creates a connection between past social structures and future innovation success. Social embeddedness in the wider field network provides enabling and constraining conditions to form new ties and subsequently repeat these ties. Through repeated ties, organizations develop joint collaboration experience that allows them to make targeted contributions to the consortium activities and to achieve innovation success. At the same time, organizational actions to form and repeat ties affect the wider field network in which these organizations are embedded. Organizations that repeat their collaborations, replicate and give new meaning to past social structures, while they simultaneously must attract new partners for future collaborations. Analyzing repeated collaboration is therefore key to our understanding of how organizations cope with the tension in balancing flexibility and stability in their innovation portfolios. Our temporal perspective on repeated collaboration in R&D consortia revealed that the timing of repeated ties and actual resource inputs is of central importance for the innovation success of the individual organization, the consortium, and the wider field network. Hence, a temporal perspective on the interrelated dynamics at these three levels – organization, consortium, and network levels – is essential for the further development of embeddedness theory and theory on innovation networks.

SAMENVATTING

Ten gevolge van globalisering, volatiele markten en snel veranderende technologieën ervaren steeds meer organisaties een toenemende noodzaak tot samenwerking met andere organisaties in gezamenlijk onderzoek. Dergelijke samenwerking kan bedrijven toegang verschaffen tot heterogene middelen en kan productiecycli en marktintroductietijden verkorten. Een van de mogelijke manieren om deze onderzoekssamenwerking te organiseren is door middel van R&D consortia, waarin universiteiten als instituten voor fundamenteel onderzoek een prominente rol vervullen. Hoewel Nederlandse universiteiten intensief samenwerken met andere partijen en tot de meest innovatieve universiteiten van de wereld behoren (CWTS, 2015; Times Higher Education, 2015), is de overdracht van academische kennis naar industriële bedrijven en daarmee de valorisatie van fundamenteel onderzoek verre van vanzelfsprekend. Integendeel, de kennisinfrastructuur tussen universiteiten en industrie is sterk afhankelijk van overheidsinterventies, zowel in termen van financiering als proactieve coördinatie.

Dit proefschrift verkent de dynamieken en het succes van universiteit-industrie samenwerking in R&D consortia die zijn gesubsidieerd door een van de oudste en meest prominente technologieprogramma's in Nederland. In antwoord op eerdere oproepen tot tijd-sensitieve theorieën over samenwerking (bijv. Albert, 2013; Ancona, Goodman, Lawrence, & Tushman, 2001; Gersick, 1991; Zaheer, Albert, & Zaheer, 1999), introduceert dit proefschrift een temporeel perspectief op herhaalde samenwerking in R&D consortia. Wij stellen dat organisaties die hun samenwerking herhalen in meerdere tijdelijke R&D consortia de duur van hun relaties met dezelfde partners verlengen en zodoende enige mate van stabiliteit creëren in hun relaties, zelfs binnen de flexibele vorm van R&D consortia. Door over de tijd samen te werken met meerdere partners in verschillende R&D consortia raken organisaties ingebed in een breder innovatienetwerk. We streven ernaar om een temporeel perspectief te ontwikkelen dat inzicht verschaft in de sociale inbedding van de participanten in de consortia, in de invloed van individuele organisaties en overheidsinterventies op de ontwikkeling van het bredere innovatienetwerk en in het innovatiesucces op organisatie- en consortiumniveau. De algemene onderzoeksvraag van deze dissertatie is dan ook: *In welke mate beïnvloedt eerdere sociale inbedding de timing van herhaalde relaties in R&D consortia en in welke mate beïnvloeden deze herhaalde relaties het innovatieve succes van de organisatie en het consortium?*

In dit proefschrift hanteren we een mixed methods benadering en combineren we longitudinale analyses van de samenwerking in R&D consortia op basis van secundaire data met kwalitatieve analyses van primaire data verkregen uit 51 interviews met consortiumleiders en consortiumleden. Elk consortium bestaat uit een academische consortiumleider die werkzaam is bij een Nederlandse Universiteit, hoofdzakelijk bij Technische Universiteiten of bètawetenschappelijke departementen van de algemene onderzoeksuniversiteiten, en een gebruikerscommissie met gemiddeld 4 á 5 afgevaardigden van industriële bedrijven of dienstverleners. We onderzochten 1715 consortia die zijn opgericht tussen 1983 en 2004 en R&D projecten uitvoerden met een gemiddelde looptijd van 4 tot 5 jaar.

We ontwikkelden een serie dynamische modellen om bestaande modellen van antecedenten en consequenties van herhaalde samenwerking in R&D consortia te verfijnen. Ons temporeel perspectief maakte het mogelijk om: (I) verschillende strategieën voor tijdgebruik door organisaties in R&D consortia te onderscheiden; (II) inzicht te verschaffen in de verklarende mechanismen van embeddedness theorie (sociale inbedding theorie) op basis van een temporeel perspectief; (III) het belang van de timing van de daadwerkelijke input van middelen voor innovatiesucces te onderzoeken; (IV) de distributie van stabiliteit en flexibiliteit over de kern en periferie van het veldinnovatienetwerk te verkennen.

Ten eerste onderzochten we de impliciete assumptie in embeddedness theorie dat de timing van herhaalde samenwerking homogeen is en hoofdzakelijk sequentieel plaatsvindt, wat leidt tot sociale inbedding over de tijd. We onderzochten hoe de kans op herhaalde samenwerking zich over de tijd ontvouwt en in welke mate de timing van herhaalde samenwerking samenhangt met de verschillende actorsets die participeren in R&D consortia. Onze resultaten tonen dat de timing van herhaalde samenwerking alles behalve homogeen is en verschilt voor verschillende fasen van herhaalde samenwerking. Actoren maken bewuste keuzes met betrekking tot de timing van herhaalde samenwerking. Dat wil zeggen dat actoren inhoudelijk te onderscheiden strategieën voor tijdsgebruik hanteren die aansluiten bij de vereisten van hun institutionele omgeving. Dit hoofdstuk breidt embeddedness theorie, zoals ontwikkeld door Granovetter (1985), uit met een voorlopige theorie over de *timing* van herhaalde relaties.

Ten tweede onderzochten we of de *vorming* en de *herhaling* van dyadische relaties tussen de consortiumleider en consortiumleden op verschillend wijze worden beïnvloed door de eerdere sociale inbedding van deze relaties. Eerdere sociale inbedding omvat de informatie en ervaring verkregen door eerdere samenwerking en vormt een belangrijke basis voor de beslissing om al dan niet een relatie te herhalen (Granovetter, 1985; Gulati & Gargiulo, 1999). Embeddedness theorie maakt echter geen onderscheid tussen sociale inbeddingseffecten op de formatie en herhaling van relaties en veronderstelt impliciet dat effecten van eerdere inbedding stabiel zijn over de tijd. Wij introduceren een tijd-sensitieve embeddedness theorie die de assumptie van stabiele temporele effecten van sociale inbedding op de formatie en herhaling van relaties ter discussie stelt en tegelijkertijd de effecten meeneemt van het genest zijn van actoren in grotere sociale entiteiten, zoals het consortium zelf en het gerelateerde veldnetwerk. Onze resultaten tonen dat effecten van eerdere sociale inbedding op de formatie van relaties verschillen van de effecten op de herhaling van relaties. Daar waar informatiebeschikbaarheid voor partnerselectie het centrale mechanisme is voor de verklaring van de formatie van relaties (Granovetter, 1985; Gulati & Gargiulo, 1999), kan de herhaling van relaties onder meer worden verklaard op basis van mechanismen als sociale integratie, uitwisseling van middelen en gezamenlijke waardencreatie. Dat impliceert dat organisaties nieuwe betekenis moeten toekennen aan bestaande sociale structuren om hun relaties te kunnen herhalen.

Ten derde onderzochten we een van de centrale assumpties van netwerk theorie (Ahuja, Soda, & Zaheer, 2012; Rawlings, McFarland, Dahlander, & Wang, 2015), namelijk dat relaties in netwerken functioneren als “leidingen” die stromen van kennis en middelen faciliteren (Borgatti & Halgin, 2011; Borgatti, Mehra, Brass, & Labianca, 2009; Podolny, 2001). In onderzoek naar sociale netwerken worden normaliter de “leidingen” gemeten en niet de daadwerkelijke stromen. Wij introduceren een contingentie theorie van herhaalde samenwerking in multi-partner R&D consortia, door de contingentie ‘niveau van participatie’ toe te voegen aan ons model van herhaalde relaties. We definiëren het ‘niveau van participatie’ als de mate waarin consortiumleden hun middelen mobiliseren om bij te dragen aan de consortiumactiviteiten. Onze observaties tonen aan dat een temporeel perspectief op de daadwerkelijke input van middelen de sleutel vormt tot het verklaren van innovatiesucces op het organisatie- en op het consortiumniveau. Organisaties gebruiken nieuwe partnerschappen om gezamenlijke samenwerkingservaring op te doen en herhalen hun samenwerking om hun middelen te mobiliseren en bij te dragen aan de consortium activiteiten. Organisaties moeten dus eerst enige ervaring opdoen om op een later moment goed geïnformeerde en doelgerichte bijdragen te kunnen leveren aan het consortium en de vruchten van deze bijdragen te kunnen plukken.

Ten vierde verkenden we de distributie van stabiliteit en flexibiliteit over de kern en periferie van het veldinnovatienetwerk. Daartoe maakten we een synthese van de mate dat een netwerk wordt gekenmerkt door een small-world structuur (Baum, Shipilov, & Rowley, 2003; Davis, Yoo, & Baker, 2003; Gulati, Sytch, & Tatarynowicz, 2012; Watts, 1999) en de positionele stabiliteit van de actoren, om zo kennis te vergaren over het succes van innovatienetwerken in de Nederlandse watersector. We beoogden meer inzicht te verschaffen in de wisselwerking tussen dynamieken op organisatie- en veldnetwerkniveau, zoals onlangs op de onderzoekagenda geplaatst werd door verscheidene wetenschappers (Ahuja et al., 2012; Amburgey, Al-Laham, Tzabbar, & Aharonson, 2008; Brass, Galaskiewicz, Greve, & Tsai, 2004). Onze resultaten tonen aan dat herhaalde samenwerking van de centrale en stabiele connectoren in het netwerk – de nuclei genaamd – kan resulteren in een stabiele kern in het netwerk die stabiliteit, behoud van ervaringen en legitimiteit biedt aan het netwerk en die een flexibele schil van nieuwe deelnemers aantrekt welke op hun beurt niet-redundante informatie aan het netwerk toevoegen. De distributie van stabiliteit en flexibiliteit over de kern en periferie van het netwerk – dat wil zeggen de ontwikkeling van een stabiele kern-flexibele schil structuur – vergroot de kans op innovatiesucces van de participerende consortia. Echter, wanneer – om wat voor een reden dan ook – de nucleus verdwijnt of wordt “weggegrepen” uit het netwerk, zal naar alle waarschijnlijkheid het complete veldnetwerk uiteenvallen.

Samenvattend kunnen we stellen dat herhaalde samenwerking een verbinding vormt tussen eerdere sociale structuren en toekomstig innovatiesucces. Sociale inbedding in het bredere veldnetwerk biedt faciliterende en belemmerende condities om nieuwe relaties te vormen en vervolgens deze relaties te herhalen. Door middel van herhaalde samenwerking doen organisaties gezamenlijke ervaring op die hen de mogelijkheid biedt om doelgerichte bijdragen te leveren aan de consortiumactiviteiten en om innovatiesucces te behalen. Tegelijkertijd hebben organisationele acties aangaande het vormen en herhalen van relaties ook invloed op het bredere veldnetwerk waarin deze organisaties zijn ingebed. Organisaties die herhaald samenwerken repliceren en geven nieuwe betekenis aan eerdere sociale structuren, terwijl zij gelijktijdig nieuwe partners moeten aantrekken voor toekomstige samenwerkingen. Het analyseren van herhaalde samenwerking is daarom de sleutel tot inzicht in de wijze waarop organisaties omgaan met het spanningsveld van het balanceren tussen flexibiliteit en stabiliteit in hun innovatieportfolio. Ons temporele perspectief op herhaalde samenwerking in R&D consortia laat zien dat de timing van herhaalde samenwerking en daadwerkelijke input van middelen van centraal belang is voor het innovatiesucces van de individuele organisatie, het consortium en het bredere veldnetwerk. Zodoende is een temporeel perspectief op de onderling samenhangende dynamieken op deze drie niveaus – organisatie-, consortium- en netwerkniveau – essentieel voor de verdere ontwikkeling van embeddedness theorie en theorie over innovatienetwerken.

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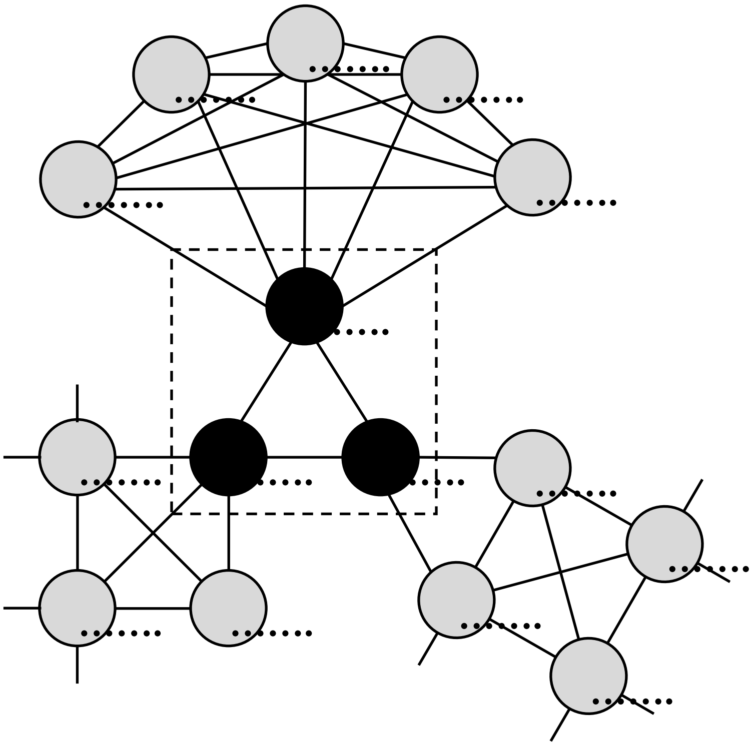
ACKNOWLEDGEMENTS



ACKNOWLEDGEMENTS

In dit proefschrift staat het belang van (herhaalde) samenwerking voor het behalen van innovatiesucces centraal. Het merendeel van de 1715 onderzochte R&D consortia gaven uitvoering aan één of meerdere promotieprojecten. Gezien ikzelf niet eerder ervaring had opgedaan met een promotieproject, kunt u zich voorstellen dat ik erg verheugd ben dat dit project tot een succesvol einde is gebracht. Echter, de belangrijkste les die we uit voorliggend en eerdere onderzoeken kunnen leren is dat het succes van een project als deze sterk afhankelijk is van de directe samenwerkingspartners (het consortium) en de relaties met het bredere sociale netwerk. Ik prijs mijzelf erg gelukkig met het consortium waarmee ik heb mogen samenwerken en het sociale netwerk waarin ik ingebed ben! Graag wil ik een aantal mensen bedanken.

Allereerst wil ik mijn promotor Marius Meeus en mijn copromotor Joerg Raab bedanken. Marius, bedankt dat je mij deze mogelijkheid hebt geboden! Als zeer betrokken en enthousiaste promotor gaf je mij de ruimte om zelf de leiding te nemen over mijn eigen project en moedigde je mij tegelijkertijd aan om continu zelfkritisch te blijven. Om te zorgen dat ik het beste uit mijzelf haalde legde je de lat soms hoog, maar je was ook bijzonder begripvol wanneer dit nodig was. Ik ben dan ook erg blij dat we onze theorie over herhaalde samenwerking in praktijk brengen nu het promotieproject afgerond is. Joerg, jij hebt mij met veel toewijding de weg gewezen in de academische wereld. We bezochten gezamenlijk verscheidene internationale conferenties, je was nauw betrokken bij het schrijven van de verschillende hoofdstukken, je begeleidde mij bij onderwijsactiviteiten en onlangs vierde je mijn bruiloft mee. Door ons gezamenlijk netwerkperspectief verliep de samenwerking meteen al erg plezierig, maar over de tijd is deze in Granovetter’s termen ‘ingebed geraakt in een hechte sociale band’, welke we hopelijk langdurig zullen voortzetten.

Ons consortium is echter niet compleet zonder Sander! Zonder jou was dit proefschrift er immers niet gekomen. Jij hebt het leeuwendeel van het werk verzet voor de database waar ook dit proefschrift gebruik van maakt. In de tijd dat wij samen op een kamer zaten waren we op sommige momenten allebei zo diep in de data verzonken dat we de buitenwereld compleet vergaten. Maar we hebben samen ook veel gelachen tijdens conferenties, borrels en pokeravonden. Bedankt voor dit alles!

I would like to thank Terry Amburgey. We first met at the EGOS swg on Organizational Network Research that you coordinated together with Joerg and Andreas and later with Barak. I admired the way you expressed your feedback in a very positive and constructive manner which made you an example for young scholars like me. Many thanks for the hospitality and warm welcome during my visit to the University of Toronto and the inspiring collaboration!

Graag wil ik ook de leden van de promotiecommissie bedanken voor de tijd die jullie hebben besteed aan het lezen en beoordelen van mijn proefschrift. Bedankt prof. dr. David

Knoke, prof. dr. Amalya Oliver, prof. dr. Joris Knoben en prof. dr. Leon Oerlemans. David and Amalya, many thanks for the time you have spent reading and reviewing my dissertation. I am honored that you are enthusiastic about joining the defense committee. Joris, ik ben blij dat jij in mijn promotiecommissie wil plaatsnemen, mede vanwege alle eerdere nuttige gesprekken, hulp bij de econometrie en de gezellige momenten tijdens conferenties. Leon, gezien jouw colleges mijn eerste interesse in sociaal netwerkonderzoek hebben opgewekt en alle latere gesprekken deze interesse verder hebben versterkt, ben ik bijzonder enthousiast en dankbaar dat jij wilt deelnemen in mijn promotiecommissie.

Ook wil ik graag dr. Eppo Bruins bijzonder bedanken voor de bereidwilligheid om te opponeren bij mijn verdediging. Ik heb de contacten met STW altijd als bijzonder prettig ervaren. Daarnaast bedank ik ook graag de 51 anonieme interviewrespondenten voor hun tijd en bereidwilligheid om mee te werken aan mijn onderzoek.

Natuurlijk wil ik ook heel graag mijn (oud)collega's bedanken voor alle hulp, adviezen, steun, koffiemomenten, borrels en andere gezelligheid! In willekeurige volgorde bedank ik Liesbeth, Franka, Aafke, Hugo, Gabi, Steffen, Stefan, Gertjan, Jac, Konstantinos, Roger, Annefleur, Rik, Patrick, René, John, John, Alice, Nicoleta, Maryse, Stanislav, Victor, Martyna, Smaranda, Folkert, Gijs, Hans, Sjo, Arjan, Daniela, Roland, Roel, Linda, Marino, Rob, Rob, Joan, Tom, Jing, Petru, Helen, Tobias, Tine, Walter, Jeroen, Evgenia, Ishani, Keith, en iedereen die ik vergeten ben te noemen.

Graag wil ik mijn paranimfen Stefan Kolenbrander en Chantal Mannak bedanken! Stefan, wij doorliepen samen met Marko, Maurice en Roeland de master organisatiewetenschappen waar een hechte vriendenkring ontstond. Filosofische discussies wisselden we af met veel gelach en gezelligheid. Deze vriendschap betekent erg veel voor mij en ik ben dan ook blij dat jij mij als paranimf steunt. Chantal, mijn zus(je), ik waardeer het erg dat jij als paranimf de familie wilt vertegenwoordigen bij deze gebeurtenis die erg belangrijk is voor mij. Ons gezin is altijd een grote steun voor mij geweest en heeft mij de ruimte gegeven om mij op deze manier te kunnen ontwikkelen. Papa en mama, bedankt voor alle liefde en steun die jullie mij geven.

Als laatste (maar aller belangrijkste) wil ik mijn vrouw bedanken! Dankzij jouw onvoorwaardelijke steun en toewijding heb ik dit proefschrift kunnen schrijven. Jij moedigde me aanvankelijk aan om organisatiewetenschappen te gaan studeren, vervolgens om te gaan promoveren, jij hielp me mijn vliegangst overwinnen, ging met me mee naar de andere kant van de wereld. Je was er altijd voor mij, tijdens leuke en lastige momenten. In dit proefschrift probeer ik een temporeel perspectief op samenwerking te ontwikkelen. Echter, onlangs hebben wij onze liefde vereeuwigd, het temporele ontstegen. Daarmee krijgt 'herhaalde samenwerking' een nieuwe betekenis: voor altijd, elke dag, met jou!